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Lectures on Telegraphy.

Duplex, Quadruplex, and other Circuits; Transformer and Testing.

(*With 33 Illustrations.*)

PUBLICATION SANCTIONED BY THE DIRECTOR-GENERAL OF TELEGRAPHS.

BEN J. STOW,
Sub-Assistant Superintendent of Telegraphs.

Calcutta:
THACKER, SPINK & CO.
1897.

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PREFACE.

THIS little book is based on the substance of the lectures delivered by the Author at Madras and Bombay in 1895, by order of the Director-General of Telegraphs; and extracts of the instructions issued by him in the *Indian Telegraphist* while Editor of that Journal.

The subjects treated on herein embrace a very simple description of the Duplex, Quadruplex and other systems of working, the Transformer and Testing, both with the Tangent Galvanometer and the Bridge.

In his endeavour to afford the subordinate staff of the Indian Government Telegraph Department a means of self-education in practical telegraphy, the Author hopes he will succeed, which alone is his object in writing this pamphlet.

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FIG. I.

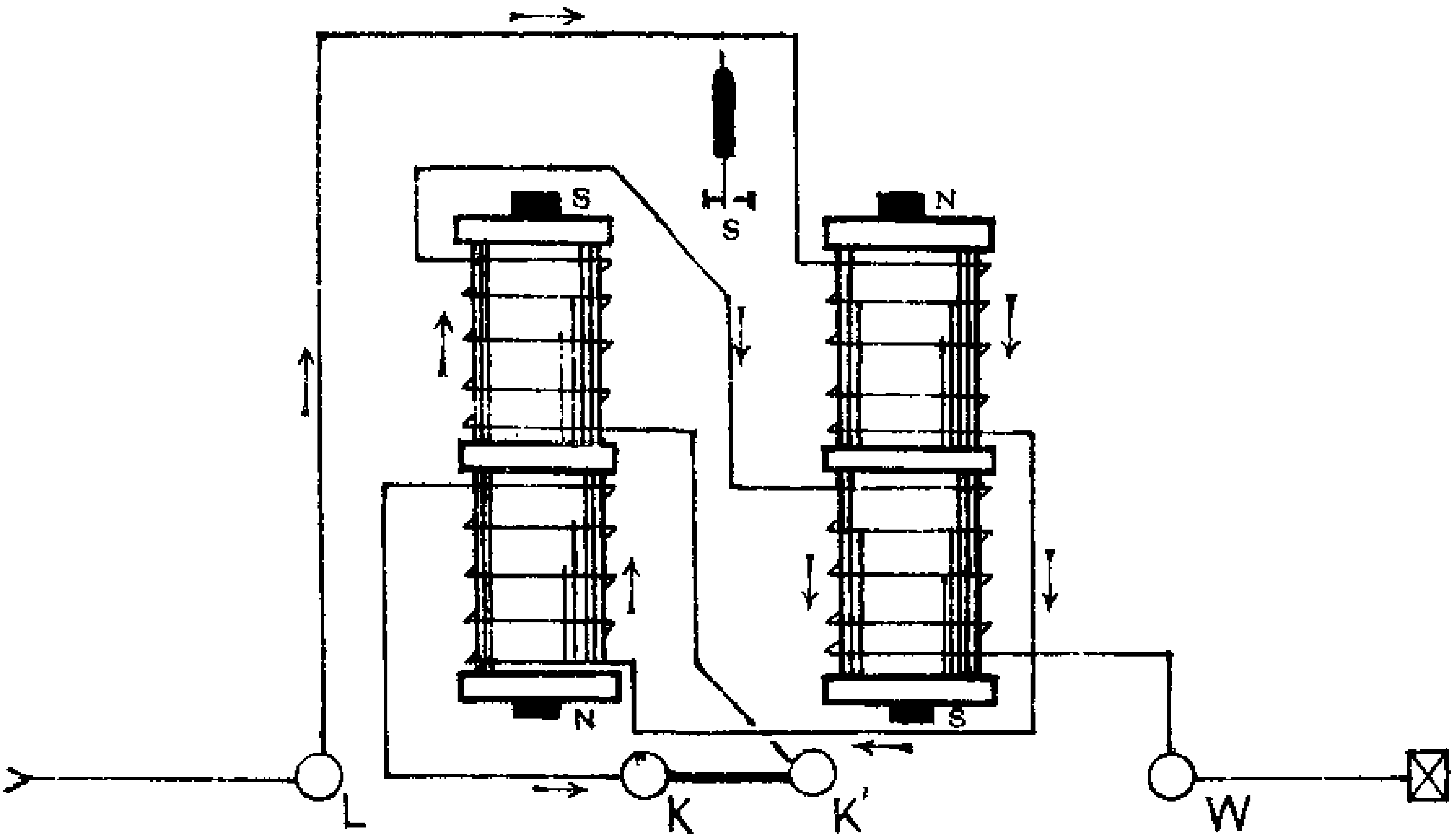
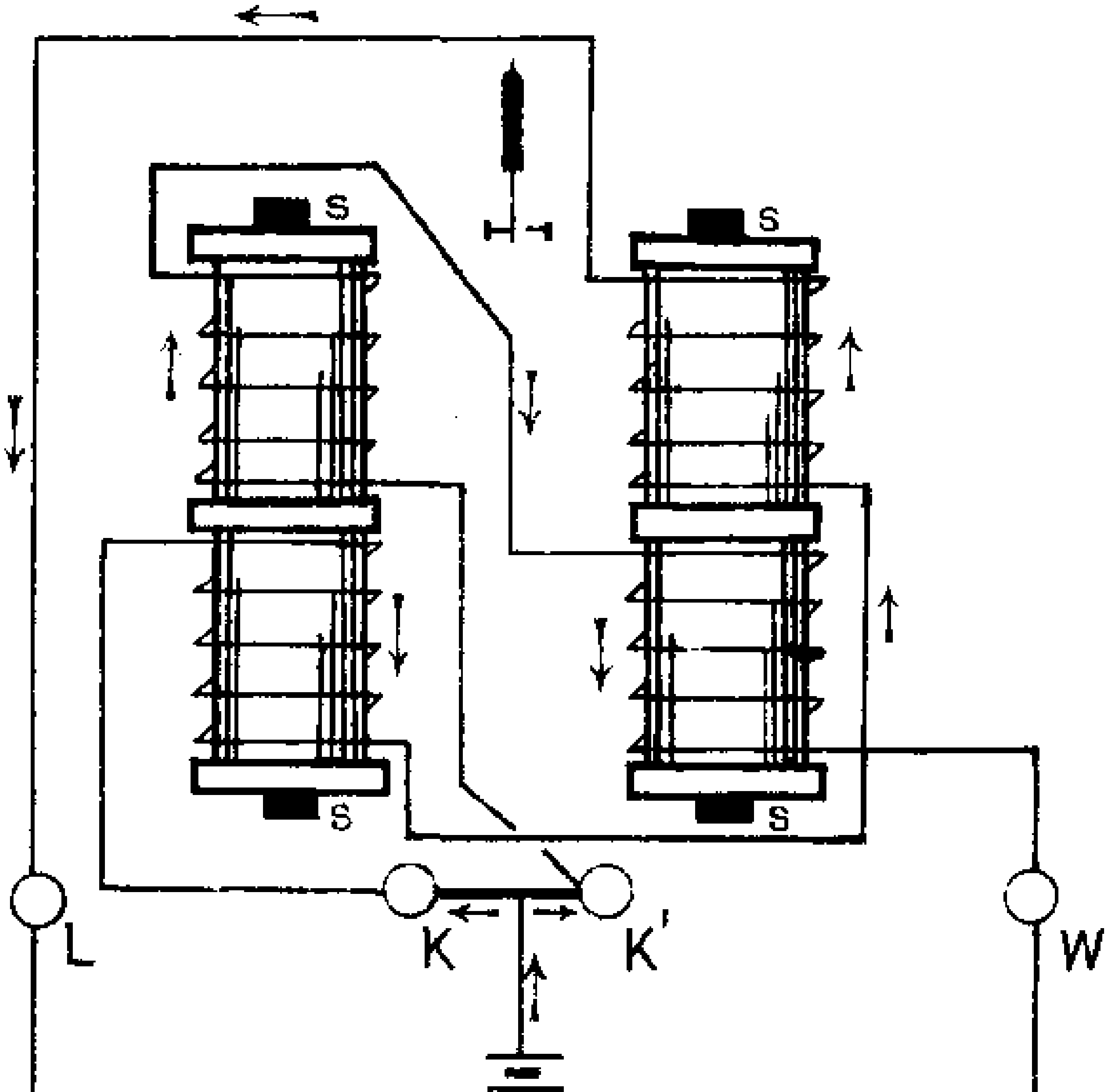


FIG. II.



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LECTURES ON TELEGRAPHY.

DUPLEX.

Action of Currents.—In a left-handed helix or spiral, that point where the positive current enters is a north pole, and where it leaves a south; but in a helix wound right-handed, like the thread of an ordinary screw or corkscrew, the effects are just the reverse.

A ready way of determining which end of a spiral has north polarity is to clasp the coil with the right hand, with the fingers pointing in the direction in which the current is flowing through the coil and the thumb extending at almost right angles to the fingers; that end towards which the outstretched thumb points has north polarity.

Our Standard Universal Relays, depending as a matter of course on the position of the tongue relative to the cores, are wound left-handed. In fact, the majority of telegraph instruments are so wound.

(2) *Action of an Incoming Positive Current on the Standard Universal Relay.*—Fig. I represents a standard universal relay, and the flow of a positive current through it as indicated by the arrows. The letters N S show the polarity of the cores.

The tongue being south is attracted by N and repelled by S; hence the polarised relay works with a positive current.

(3) *Action of Outgoing Currents on the Standard Universal Relay.*—The action of the outgoing or home current may be illus-

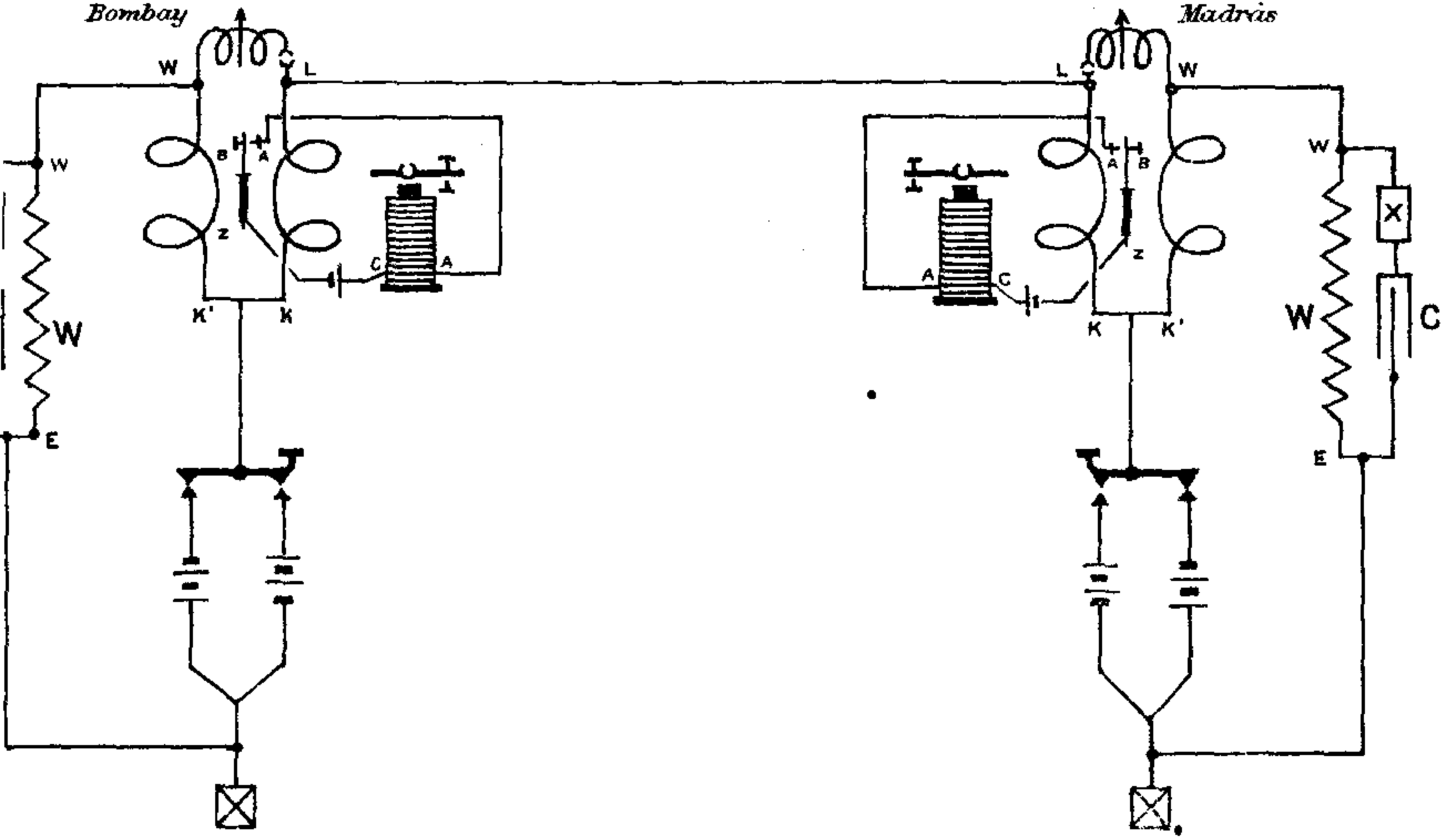
The cores nearest the tongue being S and the tongue S also, the former exert no influence on the latter, the magnetism developed in the cores by the current being equal and of the same sign in both cores ; hence we see that the application of a current of either sign at the junction $K\,K^1$ of the relay does not affect the tongue. We are now in a position to know why an *incoming* current works the relay, while an *outgoing* does not.

(4) *How two stations may be connected up for Double Current Differential Duplex Working.*—Fig. III shows exactly how two stations, say Bombay and Madras, may be connected for ordinary Double Current Differential Duplex Working.

By double current is meant an arrangement of the key, or, as in the figure, of the battery split in two ; whereby a current of the opposite sign, and therefore in a direction the reverse to the first, is sent immediately after it ; the object being not only to hasten the discharge or clearance of the line of any charge accumulated on it, but to accelerate speed, as it enables the relay tongue being placed in a neutral, that is, in a most sensitive, position ; so that when the key of the distant station, on the cessation of a signal, returns to its rest position, the reverse current drives the tongue over against its rest stop. In single current working this rest force is occasioned by the tongue being adjusted so as to be nearer one shoe of the electro-magnet than the other ; a fixed magnetic bias being thus given it against which the line current has to work.

(5) *Method of balancing a Duplex Circuit.*—The only two resistances that need adjusting at each station are the W and X boxes. The W box consists of a set of bifilarly wound resistance coils. The object of the bifilar winding is to eliminate the extra

FIG. III.



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single. By the coils being wound double the current flows in separate directions in the bobbin; the portion in one direction neutralising or eliminating the inductive effect in the other direction, *W* balances the following resistances :—

(1) The line.

(2) The line coil of distant station relay.

(3) The negative half of the distant station battery when an ordinary key is used, or the whole of the distant station battery if a reversing key is employed.

The *X* box, which may better be remembered as the *C* (condenser) box, consists of a set of resistance coils singly or bifilarly wound. It simply increases or decreases the capacity of the condensers to correspond with that of the line by inserting or removing plugs in it.

Before balancing the arrangement let each station calculate what resistance should be unplugged in *W*.

When *BY* balances, see Fig IV, he includes the circuit 1, 2, 3, in his balance and *MS* 2, 1, 4. Supposing the wire to be iron of gauge 24 or 36; now to find the resistance per mile of such a wire we would have to divide 252 (the per mile resistance of our standard wire No. 1) by 24 or 36, thus: $\frac{252}{24} = 10{\cdot}5$ or $\frac{252}{36} = 7$. If we say the 500 mile wire is of 24 gauge throughout, then, to find the total resistance of that wire, we would have to multiply 500 by 10·5; which would equal 5,250 ohms. Say we have found the resistance of the line to be 5,250, the relay in balance branch 500, and the battery 50; the total 5,800 is what each station should under these conditions unplug in starting balance: but from experience it is known that *W* at both stations is seldom or never equal; the reason and proof of this will be given later on. It has been found that a condenser of 0·75 *M F* is sufficient for a line 100 miles in length; therefore for a line 500 miles long condensers of capacity $0·75 \times 5 = 3·75$ *M F* should be employed.

The amount of condenser capacity required to balance the discharge on a circuit is a variable quantity. Less capacity is required as a rule in wet weather than in fair, the cause being due to the fact that as much of the charge is lost through leakage, only a portion of the charge in a line is discharged at the end. I would now wish you to pay particular attention as to how both *conductor* balance (*W*) and *capacity* balance (*X*) may be obtained.

Supposing *BY* is about to balance, he gives *MS Lia* and then inserts a plug in his balancing galvanometer switch; he obtains a deflection (the degree of which depends on the strength of the received current) caused by the distant station negative. Supposing the indicator has deflected to 25 degrees; on pressing his key, he will observe the indicator move to a lower or higher degree, *i.e.*, closer to or further away from zero. I may here mention that the indicator deflects to *that side of the galvanometer the negative current enters it*, or it points to the terminal connected to the line wire.

If, on depressing his key, *BY* observes the indicator move further away from zero, he should plug up *W*, and should it move closer, unplug till the indicator remains steady. Having obtained permanent (*conductor*) balance he should then adjust his condenser *capacity* by increasing or decreasing resistance *X*, which, from what experience I have had, would best be done as follows:—Give a beat; this would enable you to pass a current both to the line on one side and the condensers on the other. (See Fig. III.)

Having charged both your condensers and the line thus; now

FIG. IV.

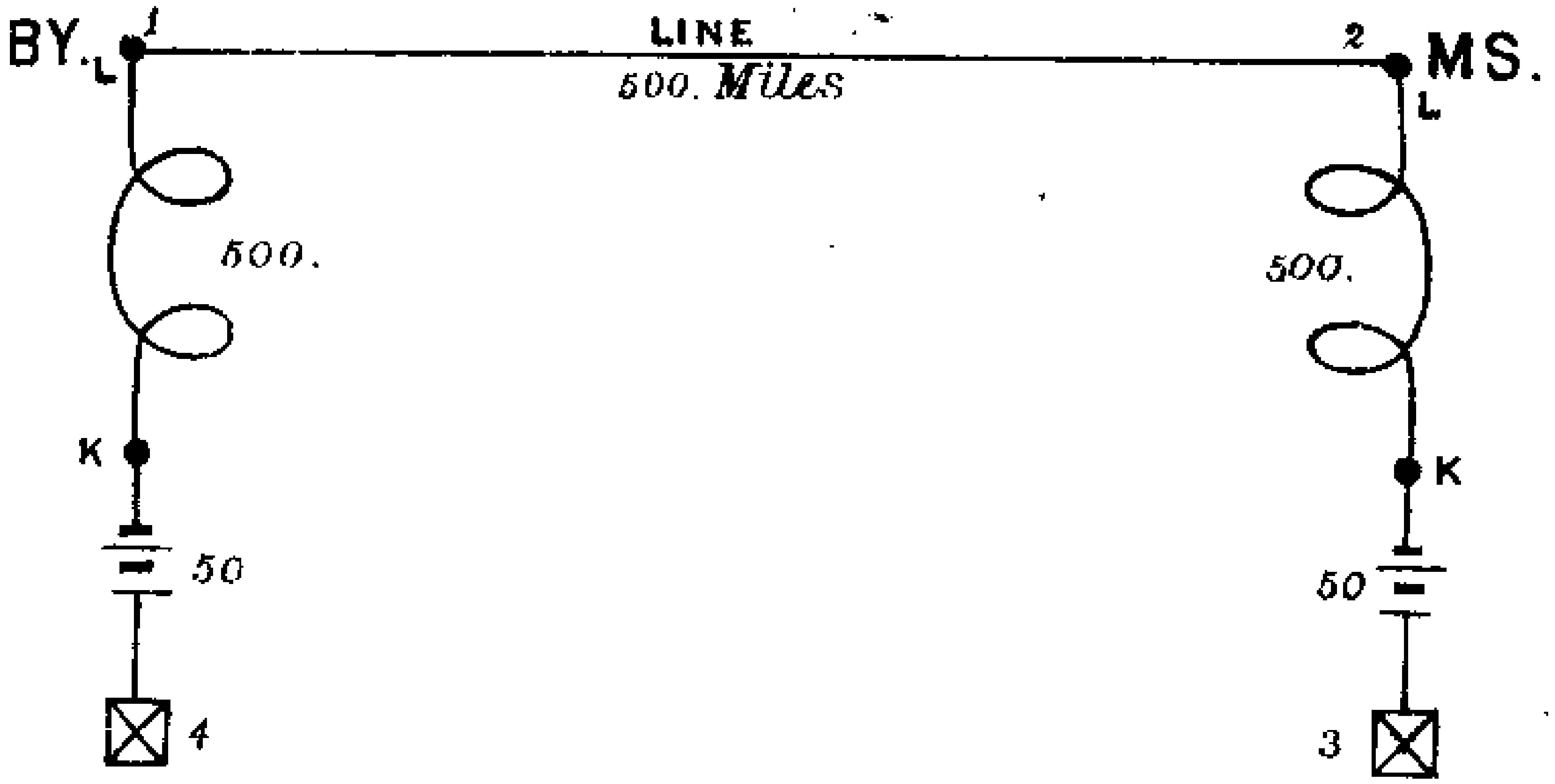
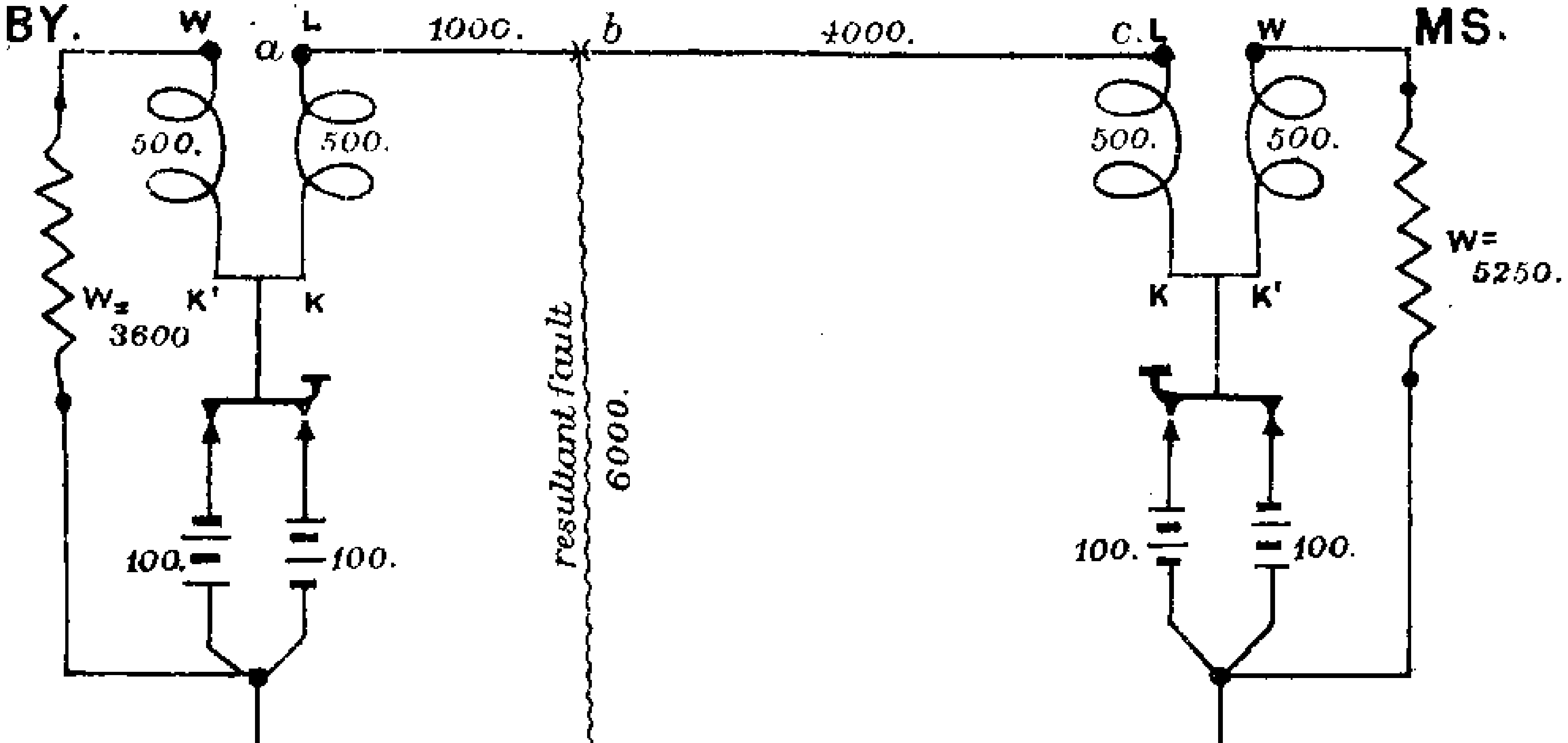

BY.
L
1
LINE
500. Miles
2
MS.
L
500.
500.
K
K
50
50
4
3

FIG. V


BY.
W
a
L
1000.
b
4000.
c.L
W
MS.
500.
500.
500.
500.
W= 3600
K'
K
K
K'
W= 5250.
resultant fault
6000.
100.
100.
100.
100.

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by the discharge. It stands to reason, if the discharge of the condensers is greater than that of the line, the indicator will kick away from zero to a degree greater than 25, and the reverse will be observed if the discharge of the line is greater. We are not in a position to alter the capacity of the line ; hence all that need be done is, when the kick is further from zero than the degree of deflection observed, to decrease the capacity of the condensers by removing plugs from the *X* box ; and if the kick is towards zero to a point less than the degree of deflection observed, to increase the capacity by inserting plugs in the *X* box. At perfect balance the indicator will remain perfectly steady if the line is free of disturbances. Madras should balance in a similar manner.

(6) *Why W at both stations is seldom or never equal.*—I shall now endeavour to show you why *W* at both stations is seldom or never equal. We can never have what may be called a perfect telegraph line, owing to it being exposed to various influences which cause a decrease in the insulation, and hence a shift in the *resultant fault*, anywhere but at the centre of conduction of the wire. Supposing we represent a circuit thus :—Fig. V.

When *B Y* balances he gets a direct resistance of that part of the circuit *a* to *b*, and then the resistances of the derived circuits *bcd* and *bf*—*i.e.*, Direct *crc a* to *b* = 1,000
Derived ,, *bcd* = 4,600
,, ,, *bf* = 6,000

To work out the derived circuit resistance you have to multiply the resistance of one of the arms of the derived circuit by the resistance of the other, and divide the result obtained by the sum

The resistance, therefore, in the *BY W* box would be 1,000 (direct *circuit* resistance) + 2,600 (derived *circuit* resistance) = 3,600. Now when *MS* balances he gets a direct resistance of 4,000 and a derived resistance of 1,600 and 6,000. Then working out the derived resistance as shewn before, we get $\frac{1600 \times 6000}{1600 + 6000} = 1{,}260$, or say 1,250 about.

Then *MS* would have for his *W* 4,000 (direct *circuit* resistance) + 1,250 (derived *circuit* resistance) = 5,250. We see now in this case *MS W* higher than that obtained by *BY* owing to the *resultant fault* being closer to *BY* than *MS*. A lower *W* at any station indicates the closer location of the *resultant fault* to it.

(7) *Action and value of the currents at different positions of the keys.*—I shall now deal with the action and value of currents (outgoing and received), both on the home and distant station relays at each position of the keys in circuit. A sketch illustrating each position would be of much advantage. I shall begin by showing you what occurs with the keys at rest, Fig. VI.

Supposing the current of each battery to be 12 *milliampères*. The arrows indicate the flow of the currents which pass through the half coil $W\,K^1$ of each relay in the non-working direction; hence the relays do not work.

Next beat at *BY*, *MS lia*, Fig. VII.

The 12 *milliampères* of positive current from the *B Y* battery would divide at $K\,K^1$ of the relay, 6 *mia* would flow through the *W* branch in the working direction $K^1\,W$ and 6 in the line branch through *K L* in the non-working direction; but the latter 6 would combine with the 6 from *MS*, making in all 12 *mia* of current in the line branch; while as indicated by the arrows we have 6 *mia* of currents in the *W* branch at *MS* flowing in the non-working direction.

FIG. VI.

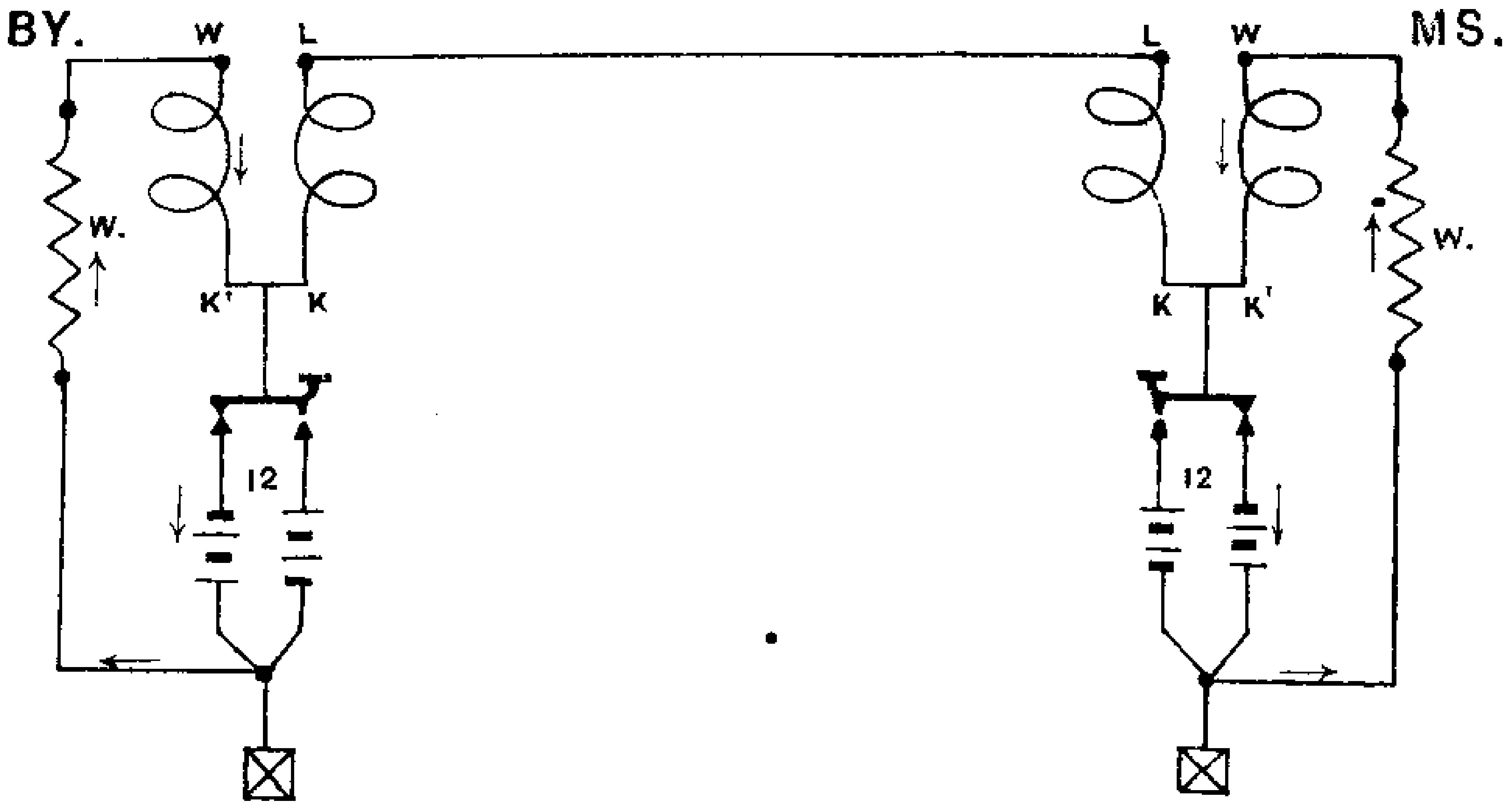

FIG. VII.

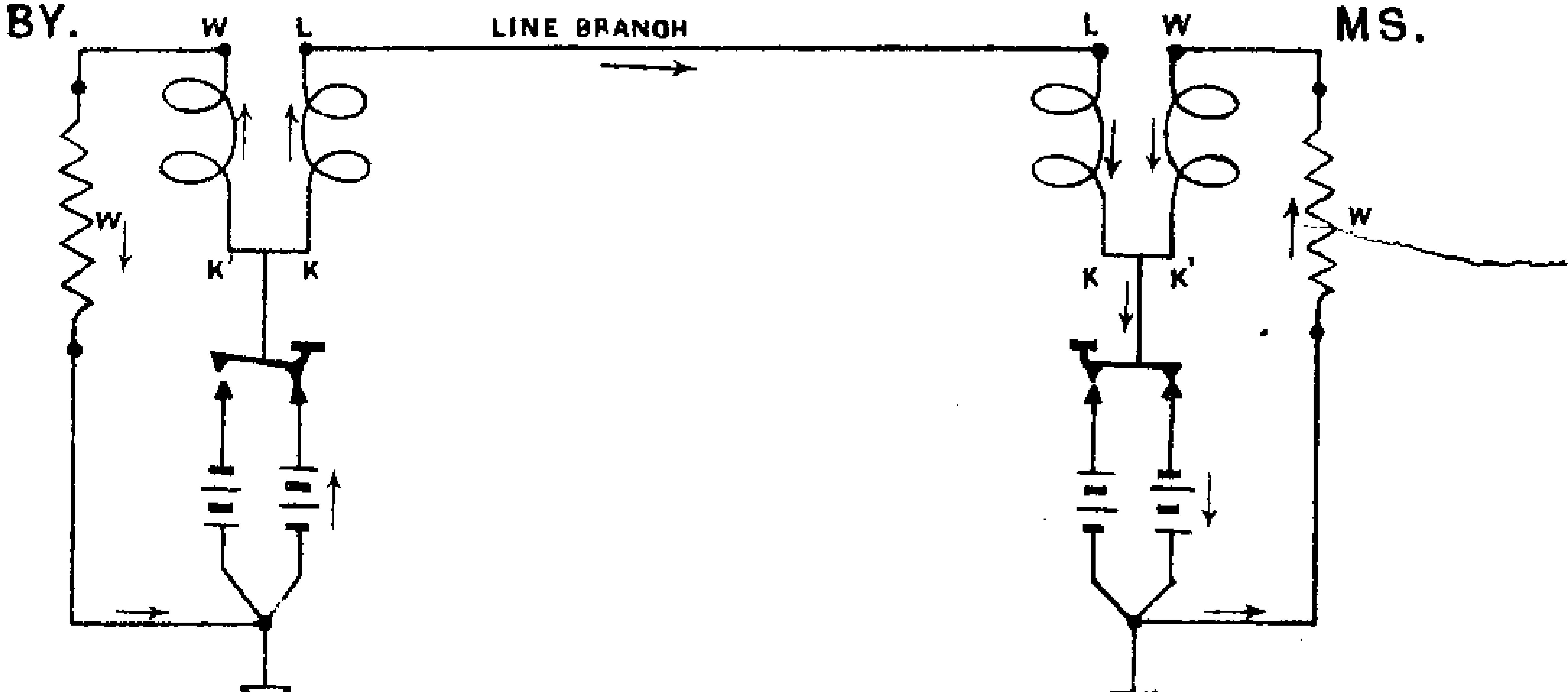

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FIG. VIII.

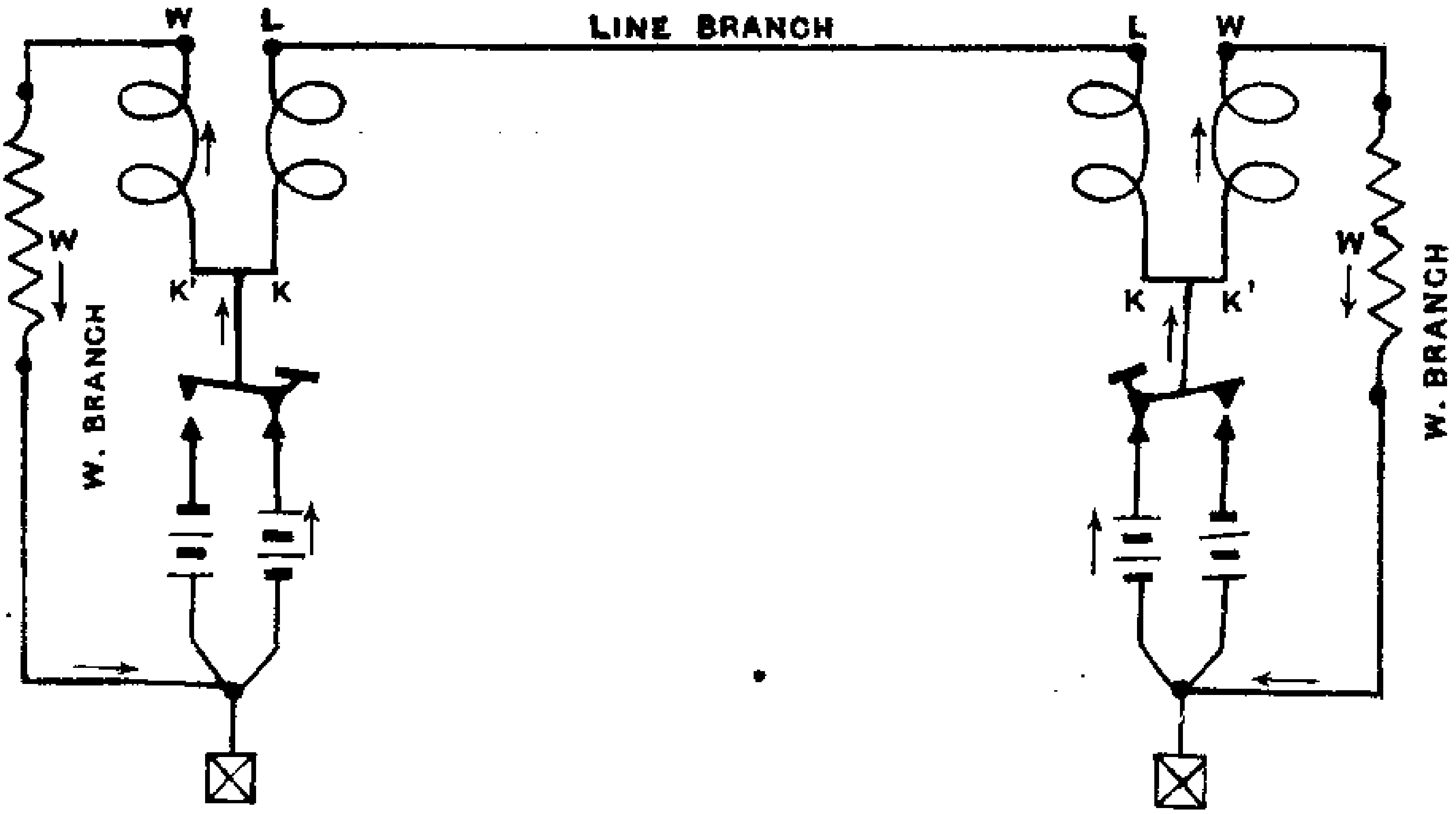
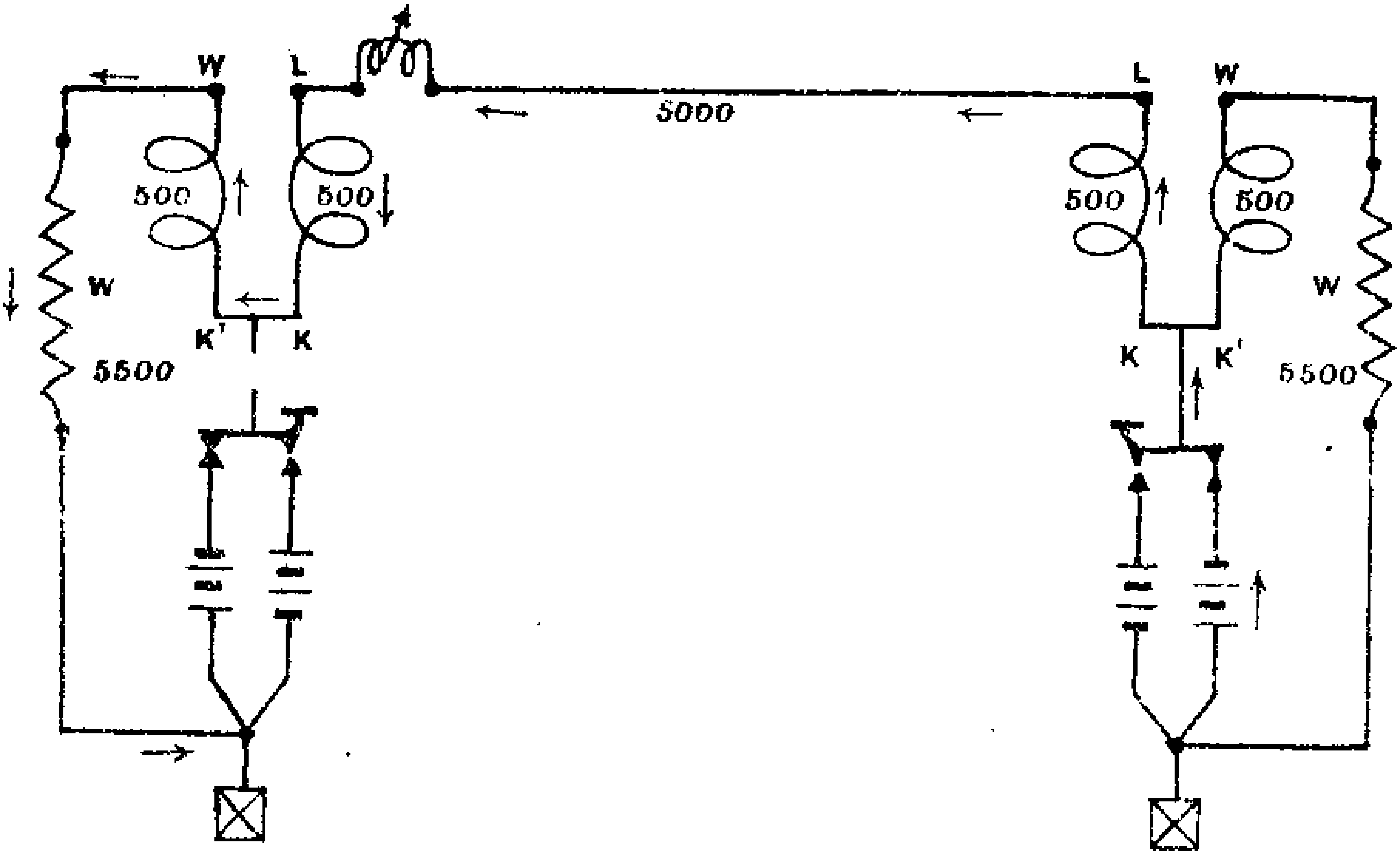


FIG. IX.



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We may sum up the currents thus :—

BY (*W* branch) 6 *mia* (working).

BY (*L* branch) 12 *mia* (non-*wkg.*) Result : 12 – 6 = 6 (non-working) ; hence *BY* relay does not work when he gives a beat.

MS (*W* branch) 6 *mia* (non-*wkg*).

MS (*L* branch 12 *mia* (*wkg.*)). Result : 12 – 6 = 6 (working); hence the *MS* relay works when *BY* gives a beat.

Had *MS* given a beat with *BY Lia*, the same effects as observed above at *BY* would have been obtained at that station and *vice versâ*.

Lastly, beats at both *BY* and *MS* (duplex), Fig. VIII.

The current is now passed through the *W* branch in the working direction of both relays, hence both relays work.

(8) *Measurements of Currents: How done.*—I shall now show you how the strength of a current measured daily by aid of the Tangent Galvanometer is not the same as that with which the relay actually works. (See Fig. IX.)

The flow of the distant negative current through the Tangent Galvanometer has been shown by arrows. If we total up the actual resistance in the circuit of the negative current when it is being measured we would have :—

Half coil distant relay	500
Line wire	5,000
Whole coil home relay	1,000
Home *W*	5,500
Total ...	12,000

but when actually working, we would have—

Half coil distant relay	500
Line wire	5,000
Half coil home relay	500
Total ...	6,000

hence to obtain the actual received current value operating in the relay, we must multiply the measured result by 2.

Fig. X will better illustrate what I have had to say on this subject.

QUADRUPLEX.

The fitting up and maintaining of quadruplex is not such a difficult matter after all, if we first make ourselves thoroughly acquainted with the principle of the system it is worked on.

(9) *Why the A relay works with a positive current (strong or weak) and the B relay with a strong current (Positive or Negative).*—At each end of a quadruplex circuit we have two relays connected up in series as per Fig. XI. One of them, the *A* relay, is a polarized instrument which works with a positive current, and owing to its high range it responds to strong and weak currents alike; hence we have the *A* relay to work with a positive current whether strong or weak. The *B* relay is a non-polarized instrument, and therefore responds either to positive or negative currents; but owing to it having an antagonist spring keeping the tongue against the rest stop, stronger currents than for the *A* relay are employed to work it satisfactorily; hence we see we must have strong currents for the *B* relay, which may either be positive or negative. We now conclude that the *A* relay responds only to positive currents,

FIG. X

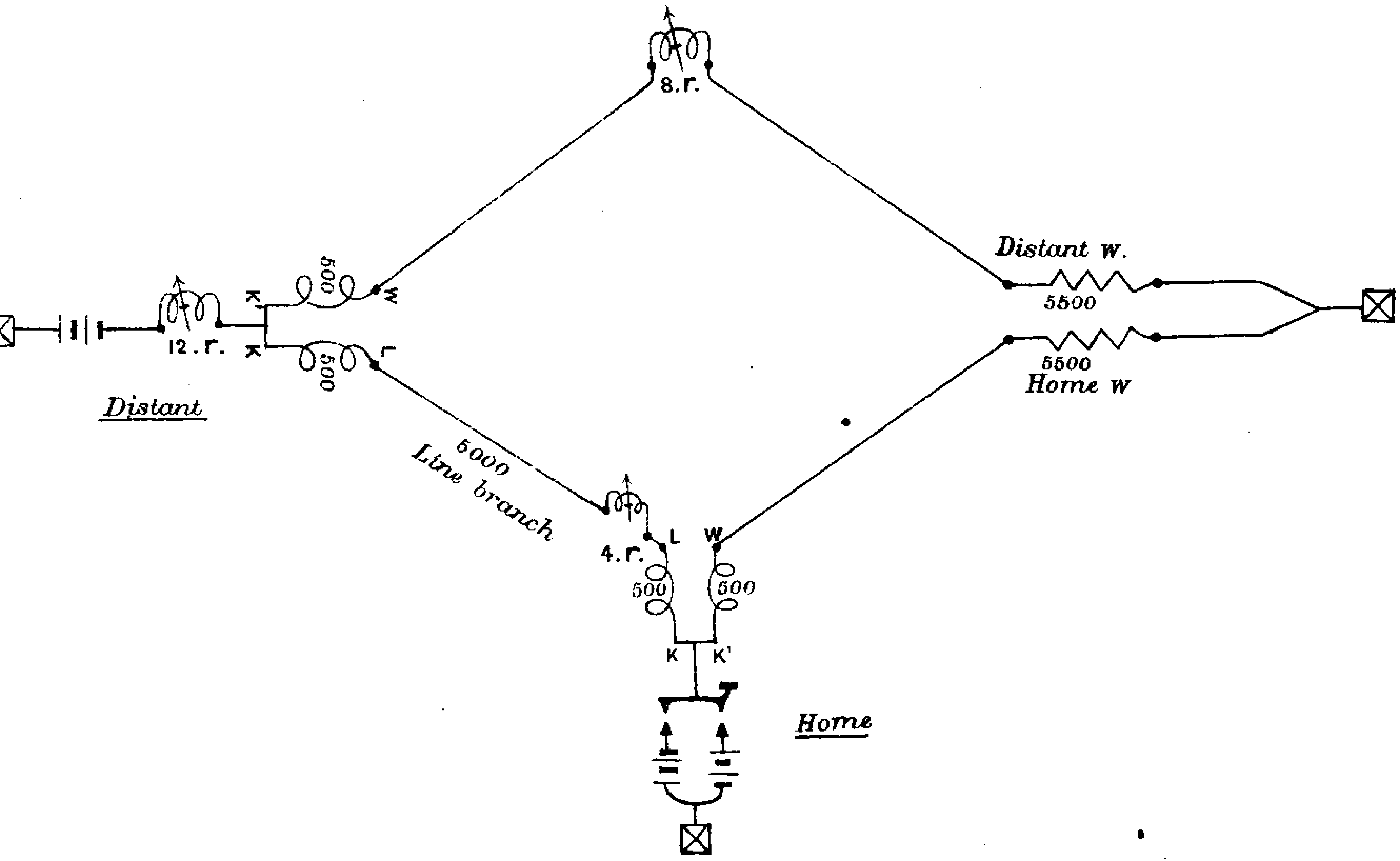
8.r.
Distant w.
5500
5500
Home w
500
500
W
L
K'
K
12.r.
Distant
6000
Line branch
4.r.
L
W
500
500
K
K'
Home

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FIG. XI.

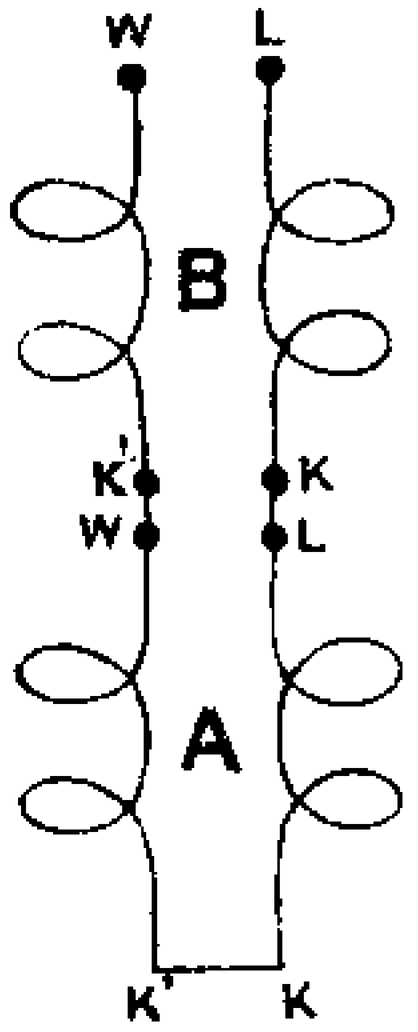
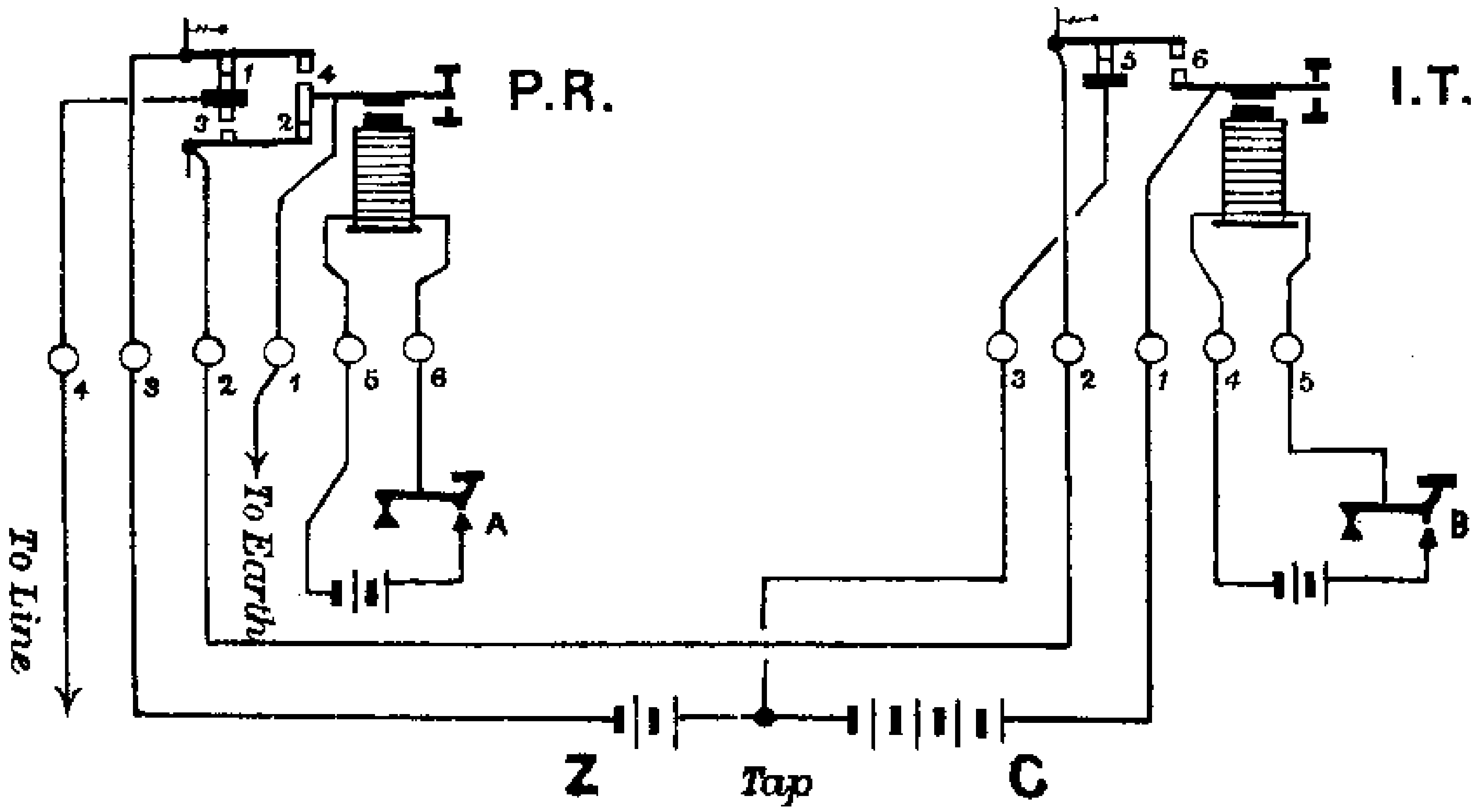


FIG. XII



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whether strong or weak, and the *B* relay only to strong currents, whether positive or negative.

(10) *How strong and weak positive or negative currents may be transmitted at will.*—It may not be quite clear to you as to how strong and weak positive or negative currents may be sent out at will; the study of Fig. XII will enable you to understand the method adopted for so doing without any difficulty. When both the *A* and *B* keys are at rest we find contacts 1 and 2 of the Pole Reverser and 5 of the Increment Transmitter closed; a small negative current flows to line through contact 1 of the pole reverser, and a small positive to earth through contacts 5 of the increment transmitter and 2 of the pole reverser. When the *A* key is worked, contacts 1 and 2 of the pole reverser are opened and 3 and 4 closed; this helps us to pass a small positive current to line through contacts 5 of the increment transmitter and 3 of the pole reverser, and a small negative to earth through contact 4 of the pole reverser. When the *A* and *B* keys are worked simultaneously contacts 1 and 2 of the pole reverser and 5 of the increment transmitter are opened, and 3 and 4 of the pole reverser and 6 of the increment transmitter closed; this enables us to send out a large positive current to line through contacts 6 of the increment transmitter and 3 of the pole reverser; the large negative is put to earth through contact 4 of the pole reverser. When the *B* key is worked alone a large negative current is passed out to line through contact 1 of the pole reverser, and the large positive is put to earth through contacts 6 of the increment transmitter and 2 of the pole reverser. We now see clearly with both keys at rest, a small negative current flows to line; with a beat on *A*, a small positive; beat on both, large positive and beat *B* only, large negative. To make it clear, when

the pole reverser is worked alone, the distant *A* relay is worked in consequence of a small positive current being sent through it; when both the pole reverser, and the increment transmitter are worked, a large positive is passed through both the distant relays and both relays work; and lastly, when the increment transmitter is worked, a large negative current is passed through the distant relays which works only the *B* relay. There, now, we have the pole reverser to work the *A* relay, the increment transmitter, the *B* relay, and both worked simultaneously to work both *A* and *B* relays.

(11) *Line Batteries and Adjustments of Y and Z Resistances.*—A word regarding the line batteries and the adjustments of the *Y* and *Z* resistances in their circuits will be found of much interest to many, particularly as most of us technical men have hitherto adjusted the *Y* and *Z* resistances by mere guess. I would ask you to give me your best attention just for a few moments. This diagram, Fig. XIII, shows you exactly how the line batteries are connected up through the *Y* and *Z* resistances. It might as well be told you that when both the keys are at rest, or when the pole reverser is worked alone, the small battery or the portion 1, 2, 3 is in circuit; but when you work both keys or the increment transmitter alone, the large battery or the portion 1, 4, 3 is in circuit; hence we may call the portion 1, 2, 3 the circuit of the *A* battery, and 1, 4, 3 that of the *B*; or in other words, about $\frac{1}{3}$ the whole battery is the *A* battery and the whole battery the *B* battery. Now as regards the adjustments of the *Y* and *Z* resistances let us consider the latter first. The *Z* resistance is called the *spark resistance*. It will be observed that each time a large battery is applied by the working

FIG. XIII

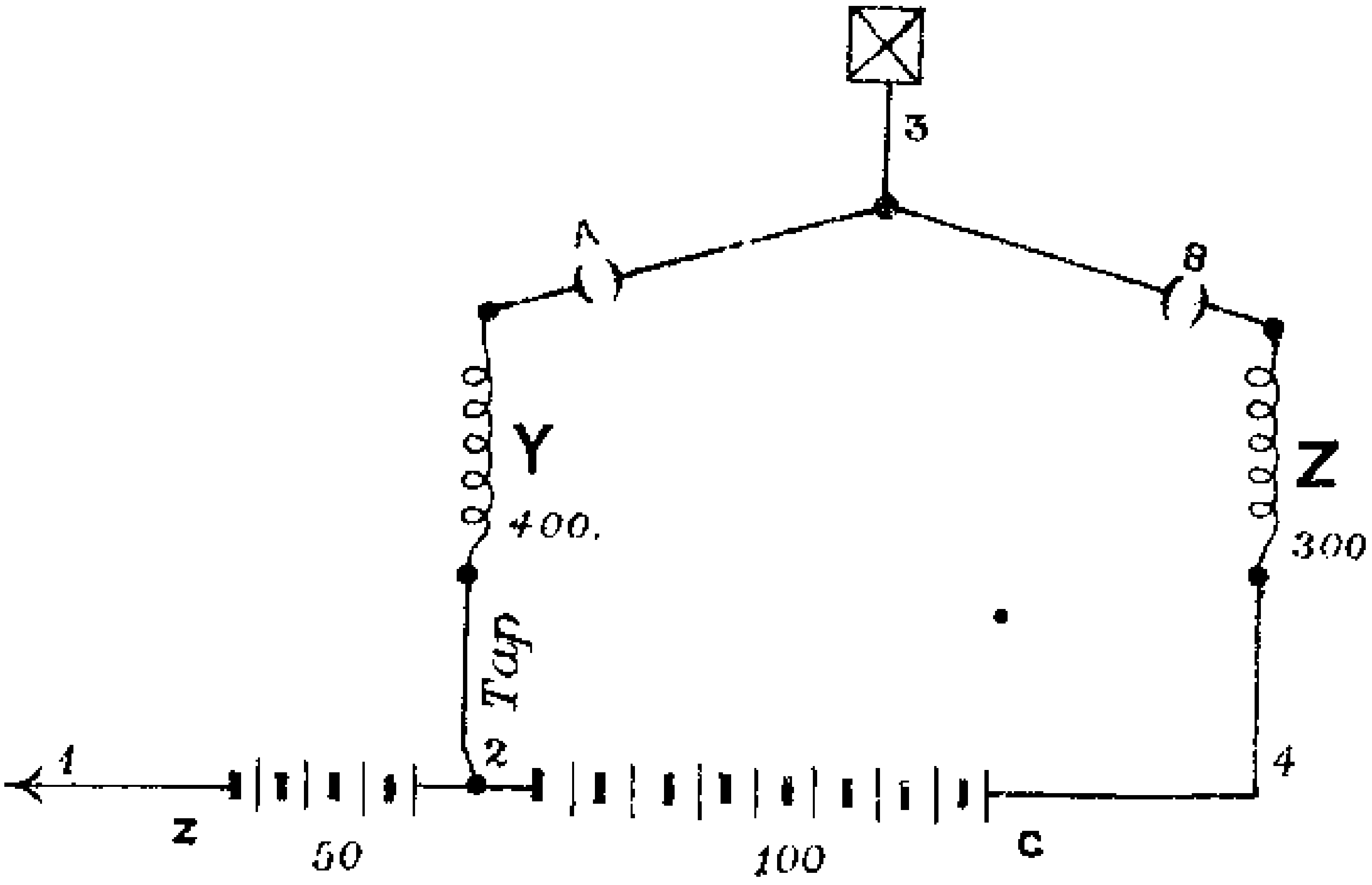
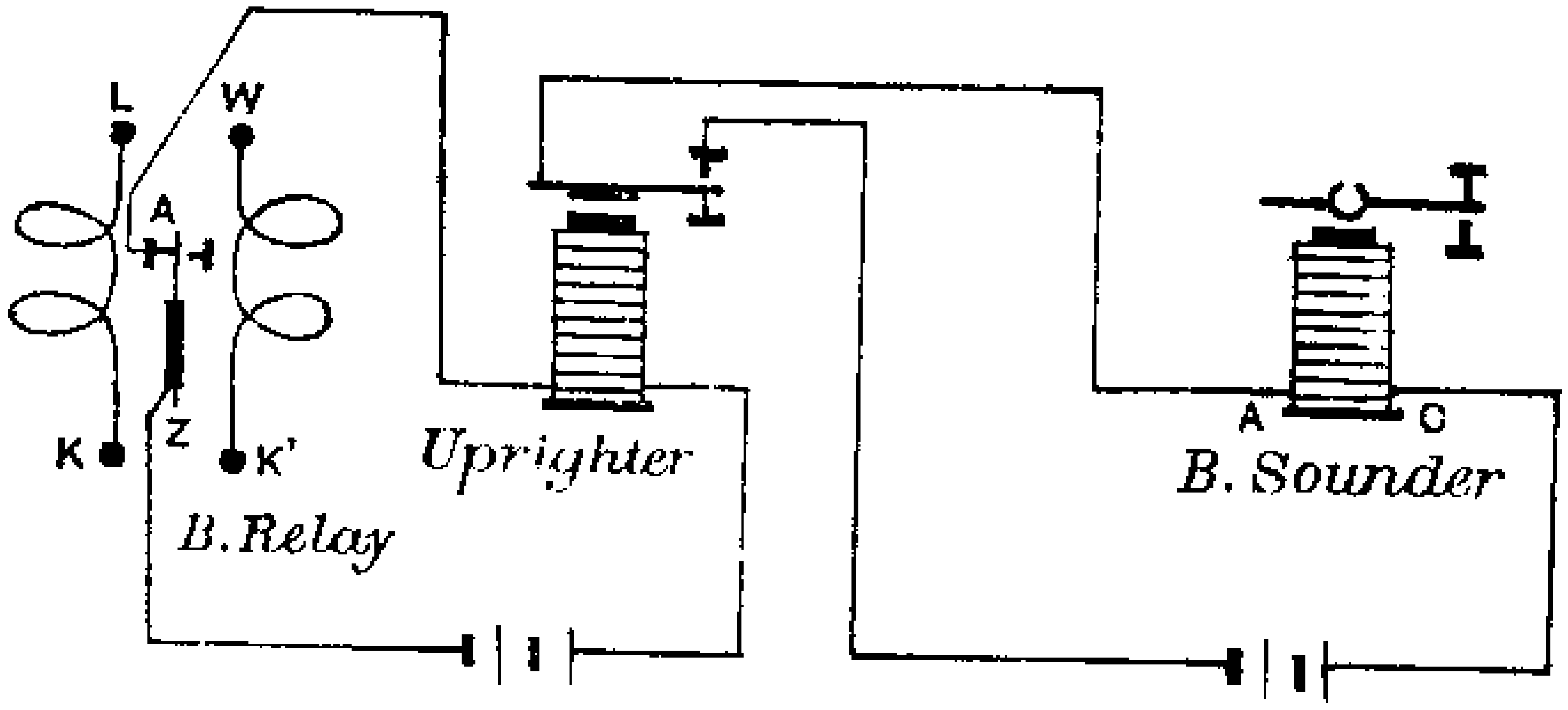


FIG. XIV



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ser, sparks are noticed at the contacts of the latter. Then, if we take for granted that all contacts are perfectly clean, all that need be done to reduce or prevent sparks is to unplug resistances in Z, which, when once adjusted, will not need to be increased in resistance till the battery is increased. Now, you are not in a position to adjust the Y resistance yourself; let the distant station do that for you in this manner. Tell the distant station to balance and you depress your B key, the battery circuit 1, 4, 3 will be included in his balance; then ask him to re-balance; this time you *Lia*, the battery circuit 1, 2, 3 will be included in his *second* balance. There should be no difference between these two balances, but if there is, the Y resistance need either be increased or decreased. If for the *second* balance more resistance has to be unplugged in the W box by the distant station than for the *first* balance, it indicates your Y resistance too high which should be plugged up, and *vice versâ*, if for the *second* balance the distant station W box has to be decreased, by plugging up. Supposing we say the resistance of the A battery is 50 and that portion of the B battery between the Tap and carbon (2 to 4), 100 and 300 had to be unplugged in Z to prevent sparking; then in the battery circuit of the home station, for the *first* balance of the distant station, we would have a total resistance of $50 + 100 + 300 = 450$; then for the distant station to obtain the same result for the *second* balance a resistance of 400 should be unplugged in Y.

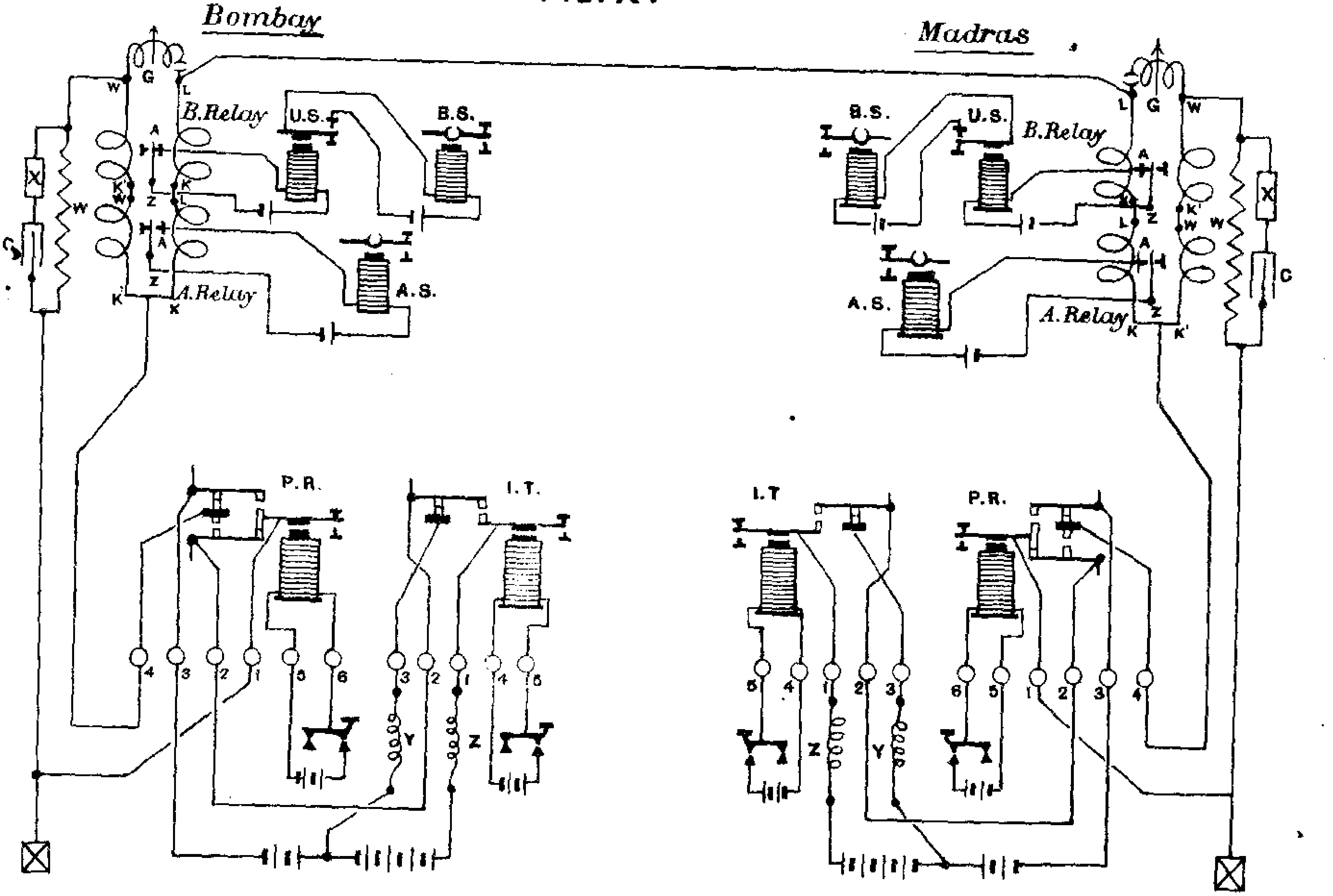
(12) *B Relay and its Local Connections.*—Here we have the B Relay, Fig. XIV, connected up with the Uprighting Sounder, and the latter in its turn with the B Sounder. When the instruments are at rest, the circuit of the uprighting sounder battery is completed by the tongue of the relay being kept against the conducting stop by

means of a spring (not shown in the sketch); the circuit of the *B* Sounder is open. On the other hand, when the *B* relay is worked by the passage of a large current through it, the tongue goes against the insulating stop, opens the circuit of the uprighting sounder battery, and closes that of the *B* sounder, working it. Some of you may be curious to know why the *B* sounder is not worked direct by the *B* relay; the reason is simply this. Each time the large battery is reversed by the working of the pole reverser, a momentary flick is observed in the *B* relay (as an interval of no magnetism in the *B* relay takes place at every reversal); but owing to the duration of the flick being so small and the action of residual magnetism in the cores on the armature of the uprighting sounder sufficiently strong, it does not respond to the flicks observed in the relay; hence any unnecessary flick is not recorded by the *B* sounder.

I shall now give you a complete diagram of two stations connected up for ordinary quadruplex working (See Fig. XV).

(13) *Method of balancing a Quadruplex Circuit.*—Here we have before us a complete ordinary quadruplex circuit, the contacts of all instruments having been cleaned, and the circuit ready for work; let both stations by calculating the resistance of the circuit unplug resistances in their *W* Boxes. Then say Bombay is about to balance his arrangement, he asks the distant station (say Madras) to send attacks, or better still *abc* on *B*, and while doing so, to depress his *A* key, and observe if his (*MS*) Pole Reverser contacts spark; if so, to increase resistance in *Z*, as explained before, till no sparks or very slight sparking is observed. *BY* next asks *MS* to give a beat on *B*, then inserts a plug in the switch of the balancing galva-

FIG. XV


Bombay
Madras
G
W
L
B.Relay
A.Relay
U.S.
B.S.
A.S.
A
K
K'
Z
X
C
P.R.
I.T.
Y
1
2
3
4
5
6

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from zero or the indicator rests against the pivot support, which is fitted at right angles to it ; all that *BY* has to do to obtain a readable deflection is to insert a resistance in the circuit of the balancing galvanometer. The deflection of the indicator of the balancing galvanometer in this case is caused by the large negative of the distant station. It is not generally known that *the indicator always deflects to that side of the galvanometer the negative current enters it*, or, in other words, it points to the side where the line wire is connected. *BY* having given a beat on *B* when starting balance, must watch carefully whether the indicator of the galvanometer moves further from or towards zero on depressing his *A* key. Supposing a deflection of 50 degrees is observed. On depressing his *A* key if the indicator moves further away from zero or to a point greater than 50 degrees, it indicates his *W* too large in comparison with the line ; all that he need do is to plug up resistances in *W*, till the indicator does not move beyond giving a kick closer to or further from zero on depressing or leaving his key alone. Should *BY* however find on starting balance that the indicator moves closer to zero to a point less than 50 degrees on depressing his *A* key, it would indicate his *W* too small in comparison with the line ; all that he need do is to unplug resistances in *W* till the indicator behaves as before explained ; this say is the condition of *BY first* balance ; now *BY* should give *MS via B*, remove the extra resistance inserted in the Galvanometer circuit to obtain a suitable deflection caused by the distant station small negative and repeat the balance, noting what he had to plug or unplug in *W* for the *second* balance. *MS* should be asked to plug or unplug *Y* as the case may be, *i.e.*, if *BY* had to unplug resistance in *W* to obtain *second* balance it would indicate *Y* at *MS* too large, and if he had to plug up it would indicate *Y* too small. The resistance in *W* for the *first* and *second* balance should be the same. Thus you see how you are able to balance three out of the four (*W*, *X*, *Y* and *Z*) resistances used in quadruplex.

I will now deal with resistance *X* (condenser balance). On obtaining permanent balance by regulating resistance *W*, continue to adjust *X* resistance: the distant station still remaining *lia.* You depress your *B* key, then the *A* key; this will enable you to give a large positive charge to the condensers on one side, and the line wire on the other; the balancing galvanometer being as it were in the centre of the two charges. Now, on releasing the *A* key, you will observe a kick. If the indicator kicks beyond the degree of deflection observed for the *second* balance (say 25) or further from zero, it would indicate your condenser capacity too large in comparison with that of the line; you therefore reduce the condensers by unplugging resistances in *X*. If, however, the indicator kicks closer to zero than the 25 degrees, it indicates the capacity of the condensers too small; the *X* resistance should then be reduced by plugging up, thereby increasing the condenser capacity. You should not be satisfied with the balance both for *W* and *X*, till the indicator of the balancing galvanometer remains perfectly steady on depressing or releasing your key on occasions, when the line is free from disturbances. Approximate balance, however, can always be obtained even if slight disturbances are observed. The effects of the currents on the home and distant station relays are similar to those explained in duplex with this difference that a higher current result is obtained as a matter of course when a higher current is applied by the working of the

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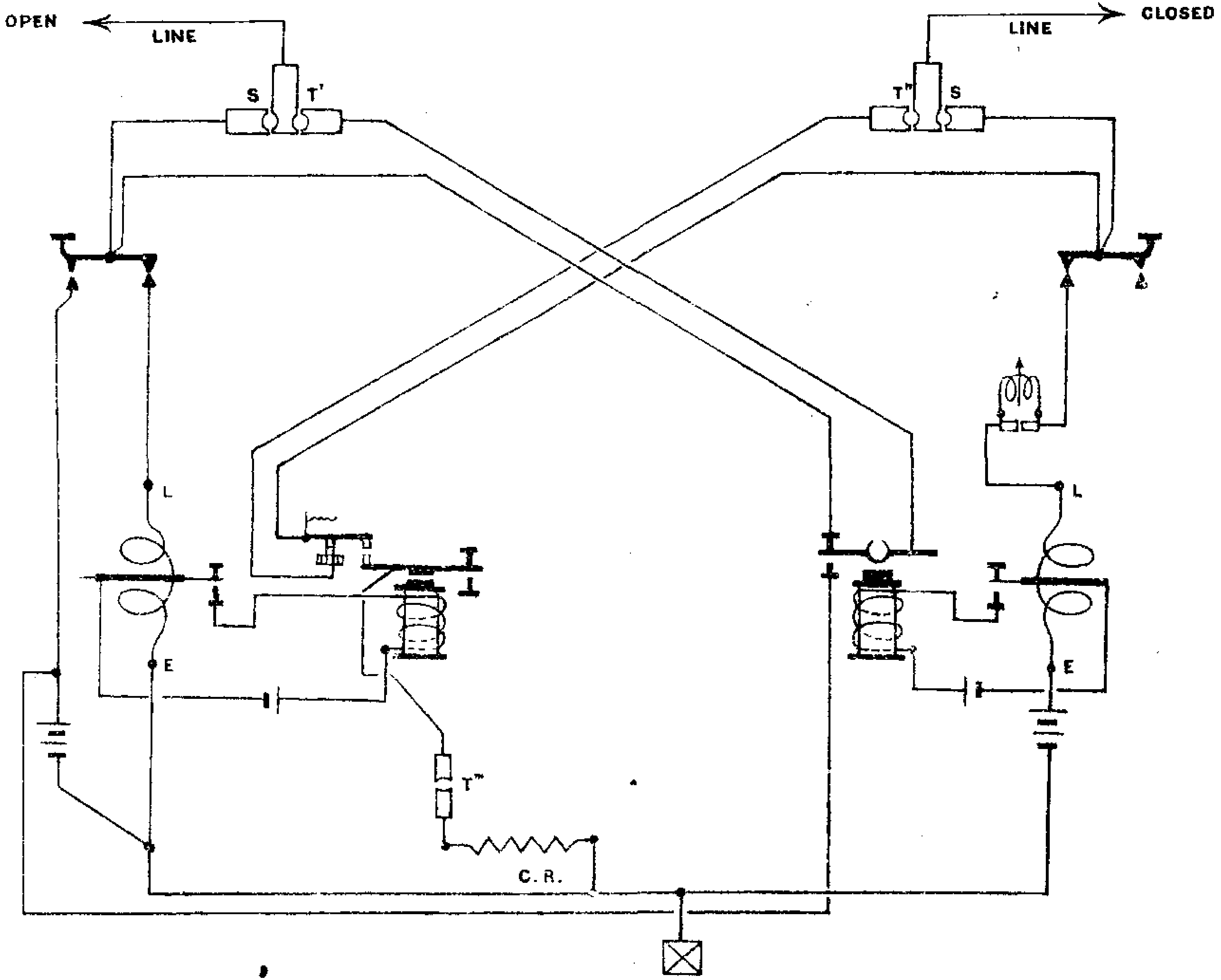
FIG. XVI



OTHER CIRCUITS.

(14) *Open-Closed Circuit Translation.*—When a key outside the translating station on the closed circuit side is depressed (see Fig. XVI) the current ceases to flow ; hence the closed circuit relay tongue at the translating station closes the circuit of the Sounder, which in its turn sends out a current on the open circuit line, and thus the distant Sounder works. When a beat is given by the distant open circuit station, the relay on the open circuit side at the translating station works the Increment Transmitter, which in its turn not only cuts off the current on the closed circuit line and causes all the instruments on the closed circuit to work thereby, but completes the circuit of the home (closed circuit) battery, through an adjustable resistance *C R*, and thus prevents the closed circuit relay at the translating station from responding to the signals made by the distant open circuit station. Thef act must not be lost sight of that when the Instruments are at rest the strength of current, which operates on the relays in circuit, is that from the combined batteries in circuit ; but when the Increment Transmitter is worked, only the home closed circuit battery operates on the home closed circuit relay ; so that the adjustable resistance *C R* helps you to regulate the strength of current to a required standard, to operate on the home relay whether from the combined batteries in circuit or from the home battery alone. The Galvanometer in circuit is merely an indicator of the strength of current. When the circuits are at the rest position, you will obtain a certain deflection on the Galvanometer ; now to equalize the strength of current through the home closed circuit relay, all you have to do is to give a beat on the Increment Transmitter and note the deflec

should remove plugs from the adjustable resistance box $C\ R$, and if smaller insert plugs in that box till you find that the same deflection is maintained whether you work the Increment Transmitter or not.

(15) *A station interpolated on a Duplex Circuit.*—The action of currents on the relays in circuit may be explained thus (see Fig. XVII):—

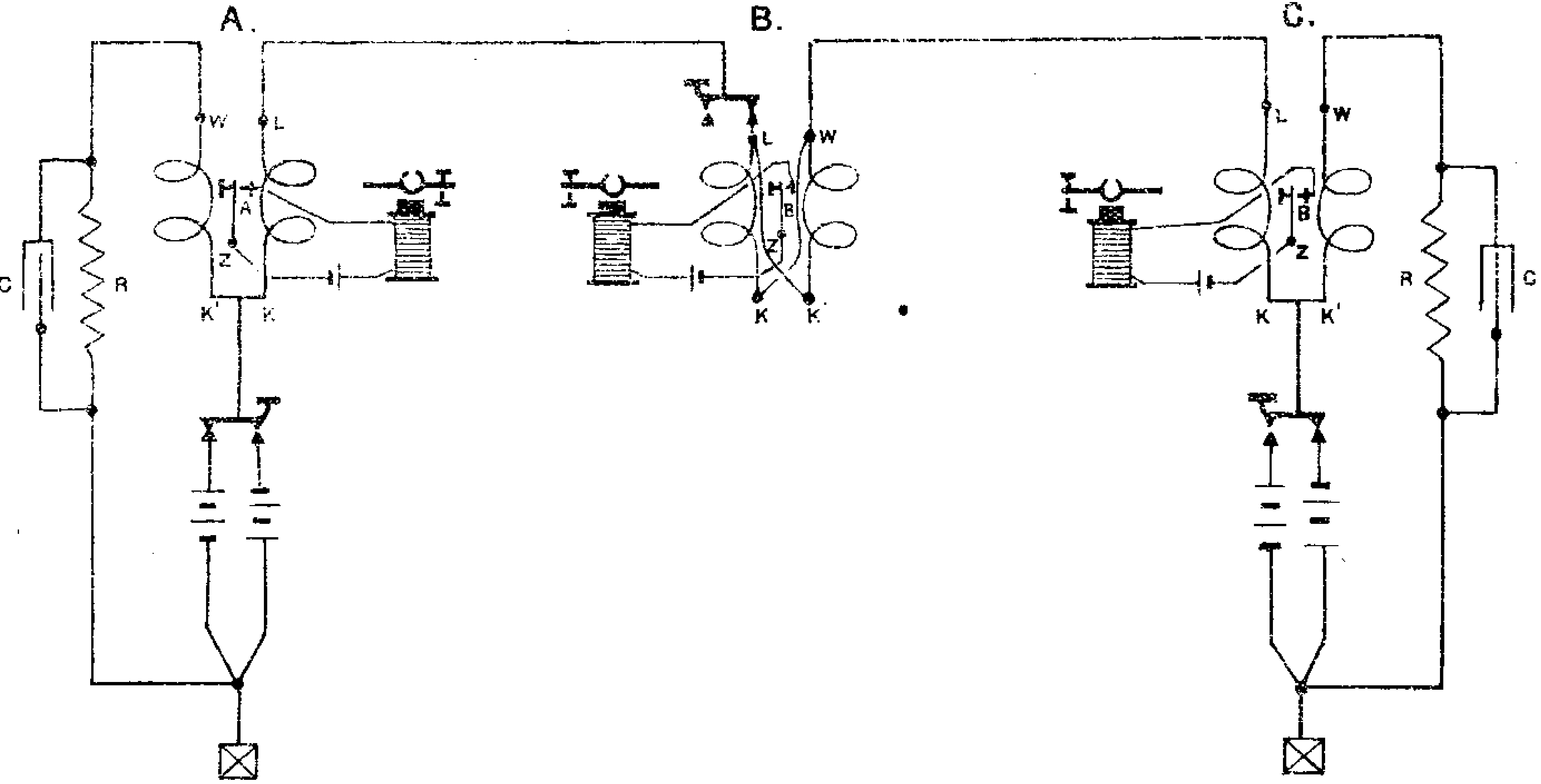
(1). When the Instruments are at rest.

(*a*) At Station *A* (supposing we have a current of 12 *milliampères* for each half battery); the line branch would have a current of 12 *mia*, but being in the non-working direction we shall term -12 *mia;* and in the *W* branch 6 *mia*, which being in the working direction we shall term $+6$; so that $-12+6=-6$, is the resultant current which would operate on the relay. The direction being non-working, the relay and hence the Sounder does not work.

(*b*) At the Intermediate Station *B*, the combined current which flows through the relay in the working direction, causes the relay tongue to rest against the work stop *A*; hence the local circuit is so connected as to be closed, on the withdrawal of the line current, by the tongue going against the usual rest stop *B*.

(*c*) At Station *C*, the line branch has, say, 12 *mia*, and being in the working direction we shall term $+$ 12 *mia;* and in the *W* branch 6 *mia*, which being in the non-working direction we shall term -6; so that $12-6=6$, is the resultant current which would operate on the relay; hence the local circuit is so connected as to be

FIG. XVII



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closed by the return of the relay tongue from stop *A* to *B*.

From the above we see why there is no beat on the Sounder at any station, although all the relays are on the closed circuit.

(2) When Station *A* gives a beat, and the other Stations *L I A*.

(*a*) At Station *A*, we would have in the Line branch, say, no current and in the *W* branch – 12; hence the resultant current on the relay being negative or in the non-working direction the relay does not work.

(*b*) At the Intermediate Station *B* (as stated above) there being no current on the line, the tongue of the relay falls back on the rest stop *B*, and closes the local circuit, hence the Sounder works.

(*c*) At Station *C* in the Line branch (as stated above) we have no current and in the *W* branch – 12 *miä* or in the non-working direction, being so, the tongue goes back to the usual rest stop *B*, which closes the local circuit and thus works the Sounder.

We now see how both the Intermediate and Distant Sounders work when a beat is given by Station *A*, while the *A* Station Sounder does not.

(3) When the Intermediate Station depresses its Key and the Terminal Stations *L I A*.

(*a*) At Station *A* there being no current in the Line branch, we have a positive current flowing through the *W* branch, *i.e.*, in the working direction of the half coils of the relay; hence the relay works.

(*b*) At Station *B* the current being withdrawn from the Line branch, by the key being depressed, the relay works.

(*c*) At Station *C*, there being no current in the Line branch, a positive current flows through the half coils of the relay in the non-working direction and causes the relay tongue to fall back on the usual rest stop *B* working the Sounder.

It is now clear how by depressing the Intermediate Station key, all the relays in circuit and hence the Sounders work.

(*d*) When Station *C* gives a beat, and *L I A* Stations *A* and *B.* (The positive batteries of Stations *A* and *C* being opposed to each other no current flows on the line.)

(*a*) At Station *A*, a positive current flows in the *W* branch, through half coils of the relay in the working direction, and works it.

(*b*) At Station *B*, there being no current in the Line branch, the tongue of the relay falls back on the rest stop *B* and closes the Sounder circuit working it

(*c*) At Station *C* a positive current flows in the *W* branch, through half coils of the relay in the working direction and holds the tongue firmly against the work stop *A*, which thus prevents the Sounder being worked.

We now see how the *A* and *B* Station Sounders work when the *C* key is depressed, while Station *C* Sounder does not.

(5) When both *A* and *C* Stations give a beat simultaneously and *L I A* Station *B* (Duplex.)

(*a*) At Station *A* in the Line branch we have, say, + 12 *mia* (6 from each station), and in the *W* branch – 6 ; hence the resultant current being + 6 or in the working direction, the relay and therefore the Sounder works.

(*b*) At Station C the direction of the currrent through the relay is reversed, *i.e.*, flows through it in the non-working direction, the tongue is passed over to the stop B and the Sounder is thus worked.

(*c*) At station C in the Line branch we have $-$ 12 *mia* (*6 from each station*) and in the W branch + 6; hence the resultant current being $-$ 6 or in the non-working direction, the tongue falls back on the usual rest stop B, which thus works the Sounder.

So lastly we see how when the keys of both Terminal Stations are depressed simultaneously, with the Intermediate Station $L\ I\ A$, the Sounders in circuit work.

In balancing such an arrangement both for *conductor* and *capacity*, results opposite to those, in the ordinary Double Current Differential Duplex System, will be obtained, *i.e.*, should on depressing the key for *conductor* balance the indicator of the galvanometer fly to a degree closer to zero, it would indicate W too large and plugs should be inserted in the W box, but if the indicator flies further from zero than the degree of deflection first observed, it would indicate W too small and plugs should then be removed from the W box. For *capacity* balance on releasing the key should the first kick on the galvanometer, caused by the discharge, be closer to zero than the deflection obtained at *conductor* balance, it would indicate the condenser capacity too large; hence it should be reduced by removal of plugs in resistance X, but should the indicator fly further from zero, it would indicate the discharge of the line too large; hence the condenser capacity should be increased by the insertion of plugs in resistance X.

In the ordinary Double Current Differential Duplex System while balancing, the batteries of the home and distant stations combine, but in the system just described (which is sometimes called Closed Circuit Duplex) the batteries oppose; hence the different effects obtained.

TRANSFORMER.

I hope next to be able to explain, in as simple a manner as possible, the ingenuity of construction and useful application of currents terminating in most satisfactory results in connection with long distance telegraphy, [illegible] India by the use of the newly invented instrument termed the Twin-Transformer.

(16) *Lenz's law.*—In all cases of electromagnetic induction, the induced currents have such a direction that their reaction tends to stop the motion which produces them. This is Lenz's law (1834).

(17) *Action of extra currents.*—Before giving you an idea as to the actual construction and working of the transformer, I wish you to understand clearly that on a line, say, of 1,000 miles in length, thus—

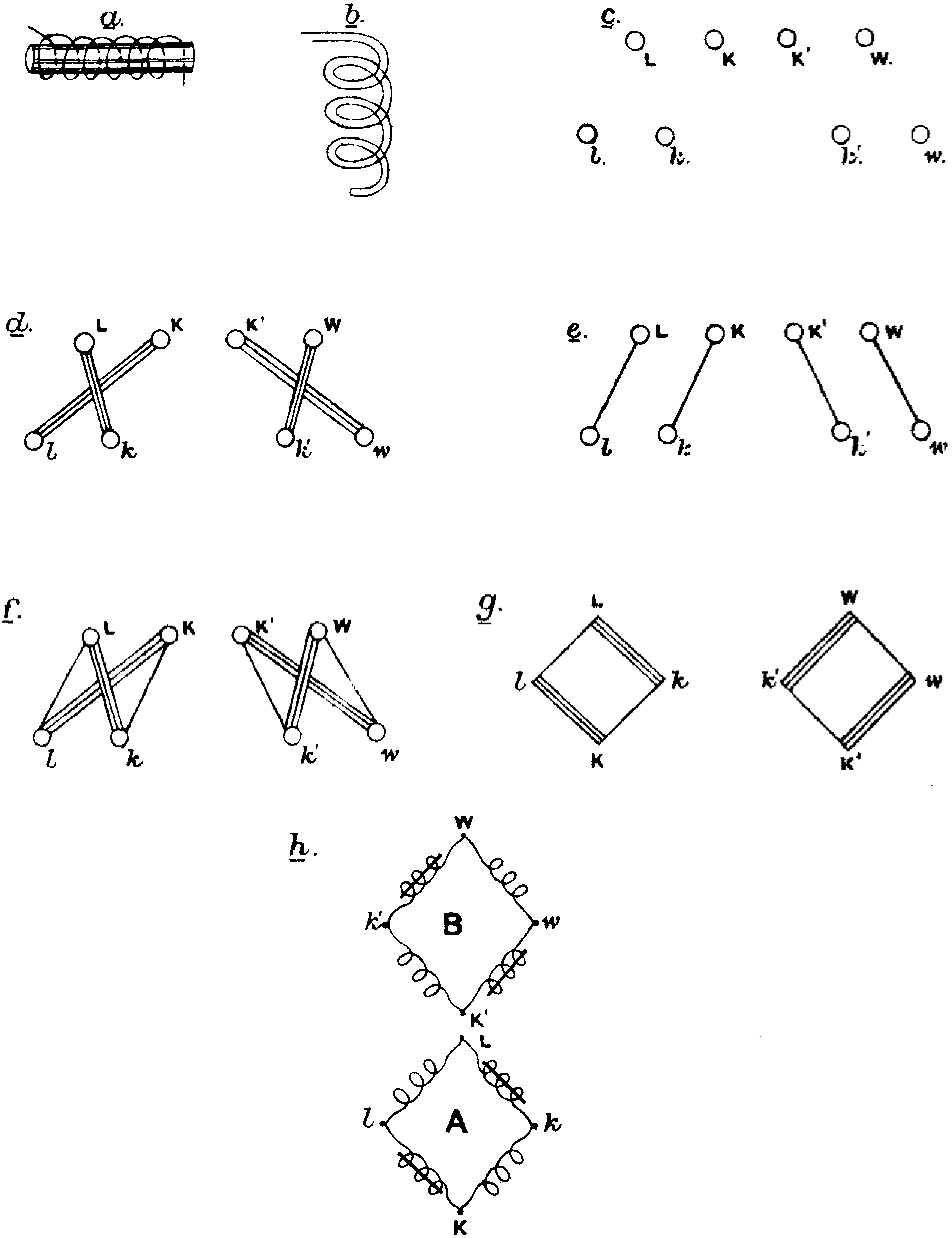
By → —————— 1,000 miles —————— ← *Ms*

a current started at BY would not only have to overcome the resistance of the circuit but to fight, as it were against a current at the distant end ; so we see that on starting a current it is opposed by another at the distant end and immediately the primary or current from BY is withdrawn an extra current flows in the same direction as the primary current, thus :—

By —————————————— → *Ms*

These two extra currents, one opposing the primary current on its

FIG. XVIII


a.
b.
c.
L
K
K'
W.
l.
k.
k'.
w.
d.
L
K
K'
W
l
k
k'
w
e.
L
K
K'
W
l
k
k'
w
f.
L
K
K'
W
l
k
k'
w
g.
L
l
k
K
W
k'
w
K'
h.
W
k'
B
w
K'
L
l
A
k
K

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way to the distant station, and the other flowing in the same direction on its withdrawal, the inventor of the transformer (Mr. W. F. Melhuish) has most ingeniously turned to good account as will be explained later on. I shall now show you how the transformer or rather the Twin-Transformer is constructed. In its construction you will observe that much care and attention has been paid to bring before the public a perfect instrument.

(18) *Mechanical construction of the Twin-Transformer.*—A twin-transformer has say 8 coils which are ample, I think, for our purposes. Of these 8 coils, four are wound round an iron core (see Fig. XVIII (*a*)), these being wound round an iron core get highly intensified and are therefore capable of sending out transient currents. Such being the case I shall term them *Transient Current Cells.*

Four other coils bifilarly wound (see Fig. XVIII (*b*)) are void of self-induction, which may be termed *Non-Inductive* or *Dead Resistance Coils.* This instrument has 8 terminal screws. Now I wish you to pay particular attention as to how I connect up the four *transient current cells* and the four *dead resistances* referred to before to these eight terminals. Supposing we put down the terminals as in Fig. XVIII (*c*).

$L\ K\ K^1\ W$ (large letters) and $l\ k\ k^1\ w$ (small letters) and take the *transient current cells* first and connect them to the terminals as in Fig. XVIII (*d*).

1*st* between	L (large)	k (small)
2*nd* ,,	K (,,)	l (,,)
3*rd* ,,	K^1(,,)	w (,,)
4*th* ,,	W(,,)	k^1(,,)

Next we connect up the four *dead resistances* as in Fig. XVIII (*e*).

1*st* between L and l (large and small)
2*nd* ,, K ,, k (,, ,,)
3*rd* ,, K^1 ,, k^1(,, ,,)
4*th* ,, W ,, w (,, ,,)

Putting the two figures together we have Fig. XVIII (*f*) broad lines representing the *transient current cells* and the narrow ones *dead resistances*. The two figures may be better remembered as shown in Fig. XVIII (*g*).

The two angles lKk and $k'K'w$ have been placed immediately opposite their corresponding angles lLk and $k'Ww$ respectively.

We have now before us two figures which actually represent two transformers and must devise some means of putting them so together as to form one instrument and yet one branch should act inductively on the other. As we see the recently constructed instrument in the shape of a box, let us imagine the portion marked A (see Fig. XVIII (*h*)) to be the box and B the lid.

(*Transient current cells* and *dead resistances* have been inserted.)

On closing the lid B over the box A and interlocking the *transient current cells* in A with those in B, keeping the *dead resistances* apart, we obtain Fig. XIX.

(19) *The Twin-Transformers.*—The figure indicated by broad lines represents the L branch portion of the twin-transformer and that by the narrow lines the W branch. We have now before us a complete diagram of the twin-transformer. The broad-lined figure acts inductively on the narrow-lined one when a current enters at L and leaves at K, but one acts inductively on the other when the home

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current enters either at *K* or K^1, and leaves at *L* or *W* respectively. I shall now endeavour to explain to you the effect of the incoming or primary current through the twin-transformer, first **at make** and then **at break** or in other words when a current is *first started* and then *withdrawn.* Here we have again a correct representation of the twin-transformer (Fig. XX) with the line branch primary coil of the relay, and both the line and *W* branch secondary coils of the relay shown for duplex working.

(20) *Action of an incoming current on the Twin-Transformer.* **At make**.—On a current being sent from the distant station, it enters the twin-transformer at the point *L* ; the arms *LlK* and *LkK* being equal, the current divides equally between the two and flows to earth through the relay from screw *L* to *K* (primary circuit). The *transient current cells a* and *b* start each a current in the direction indicated by broad arrows.

The circuit of the transient current cell *a* can only be completed in the triangle *Llk*, and that of *b* in the triangle *lkK*. Bearing this in mind we see clearly the cells *a* and *b* complete their circuits through one of the secondary coils of the relay in the direction *lk* (working) ; then by induction currents are started in the *W* branch (narrow lines) flowing in the same direction as the transient current, *i.e.*, k^1 *w* of the other secondary coil as indicated by light arrows. We now have :—

1*st*, *Primary Current* flowing through both arms *LlK* and *LkK* of the transformer and through the primary coils *LK* of the relay (working direction) to earth.

2*nd*, *Transient Current* flowing in the triangles *Llk* and *lkK*, including the secondary coils *lk* of the relay (working direction).

3rd, Induced Current flowing in the triangles $K^1 k^1 w$ and $k^1 w W$, including the secondary coils $k^1 w$ of the relay (working direction).

By summing up the above we have **at make** three currents or forces.

(1) primary, (2) transient and (3) induced acting on the relay tending to send the tongue with great force against the work stop.

(21) *The effect on the transformer at the withdrawal of the primary current.*—**At break** (reproducing the same diagram) we have Fig. XXI.

The broad arrows indicate the flow of the transient currents started by the cells *a* and *b* in the same direction as the primary current, and which complete their circuits in the triangles *klL* and *Kkl* flowing through one of the secondary coils of the relay in the direction *kl* (non-working) ; then by induction, currents are started and flow in the direction indicated by light arrows in the triangles $wk^1 K^1$ and Wwk^1, passing through the other secondary coils of the relay in the direction *wk* (non-working). We now have—

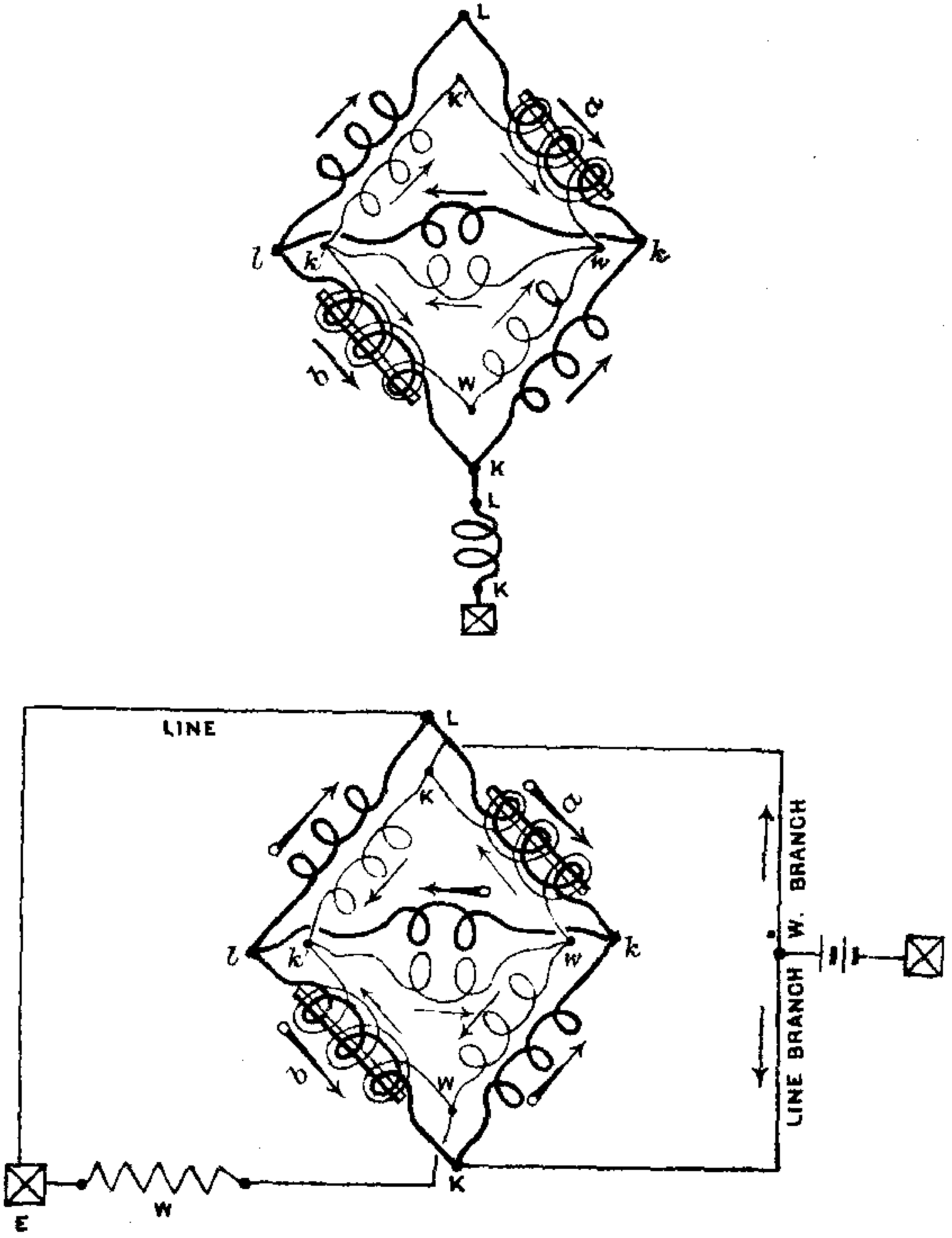
(1) *Transient current* flowing in the triangles *klL* and *Kkl*, including the secondary coils *kl* of the relay (non-working direction).

(2) *Induced current* flowing in the triangles $wk^1 K^1$ and Wwk^1, including the secondary coils wk^1 of the relay (non-working direction).

(3) The *force of restitution* in the polarized relay and the *spring* in the non-polarized relay.

By summing up the above we have **at break,** three forces also ; (1) transient current, (2) induced current and (3) the force of restitution in a polarized relay and the spring in the non-polarized

FIG. XXI



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relay ; so that either **at make** or **at break** we have three forces which tend to throw the tongue of the relay with great force either against the work or the rest stop ; hence we are in a position to work the longest circuit with the greatest possible speed satisfactorily, by the aid of the twin-transformer.

(22) *The effect of outgoing currents on the Twin-Transformer.*—A word or two more will enable you to understand the effect of the outgoing or home current on the twin-transformer. Reproducing the twin-transformer sketch once more (Fig. XXII).

At Make.—The outgoing current traverses the two arms of both the bridges simultaneously. In the *L* branch it enters at *K* and leaves at *L*, and in the *W* branch it enters at K^1 and leaves at *W*. On the circuit of the primary current being completed in the *L* branch of the twin-transformer, transient currents are started and flow in the direction indicated by broad arrows (thus o⟶). On the other hand, on the circuit of the primary current being completed in the *W* branch of the twin-transformer, transient currents are started and flow in the direction indicated by arrows (thus ⟶). We now see that while in the *L* branch we have the transient current flowing through the secondary coils of the relay in the direction *kl* (non-working direction) in the *W* branch it flows from k^1w (working direction). The flow of currents being through equal coils but opposite in direction the effects are *nil* on the relay. **At break** we have effects exactly opposite the above.

(23) *Name applied to a Duplex or Quadruplex System having a Twin-Transformer in Circuit.*—A very appropriate name has been applied to this system of telegraphy. As I said before, in explaining the action of the primary current **at make,** we have three currents or forces acting on the relay, and **at break**

also three ; further since the most important instruments employed are—

for Duplex :—
- (1) Transformer,
- (2) Relay,

for Quadruplex :—
- (1) Transformer,
- (2) *A* Relay,
- (3) *B* Relay,

all double or twin, the system has been called in reference to duplex "*triple-current-acting or twin-duplex*," and quadruplex, "*triple-current-acting or twin-quadruplex*."

(24) *Triple-current-acting or twin-duplex system.*—Instead of the ordinary relay in duplex we employ a twin-transformer and twin-relay in triple-current-acting or twin-duplex system. The connections will be clear on reference to Fig. XXIII.

(25) *Triple-current-acting or twin-quadruplex system.*—In triple-current-acting or twin-quadruplex system, Fig. XXIV illustrates the connections necessary between the twin-transformer and twin-relays ; all other connections being the same as in ordinary quadruplex.

(26) *Method adopted for varying the strength of a current through the relays.*—Experiments were tried with a rheostat connected up between *L* and *W* of the *B* relay, which enabled us to vary the strength of the current through both relays ; but the increase or decrease of the rheostat resistance, which meant the increase or decrease of current, was more marked in the *B* relay. The object was to avoid unnecessary interference with the micrometer screw of the *B* relay. When once a suitable adjustment was obtained

FIG. XXIII

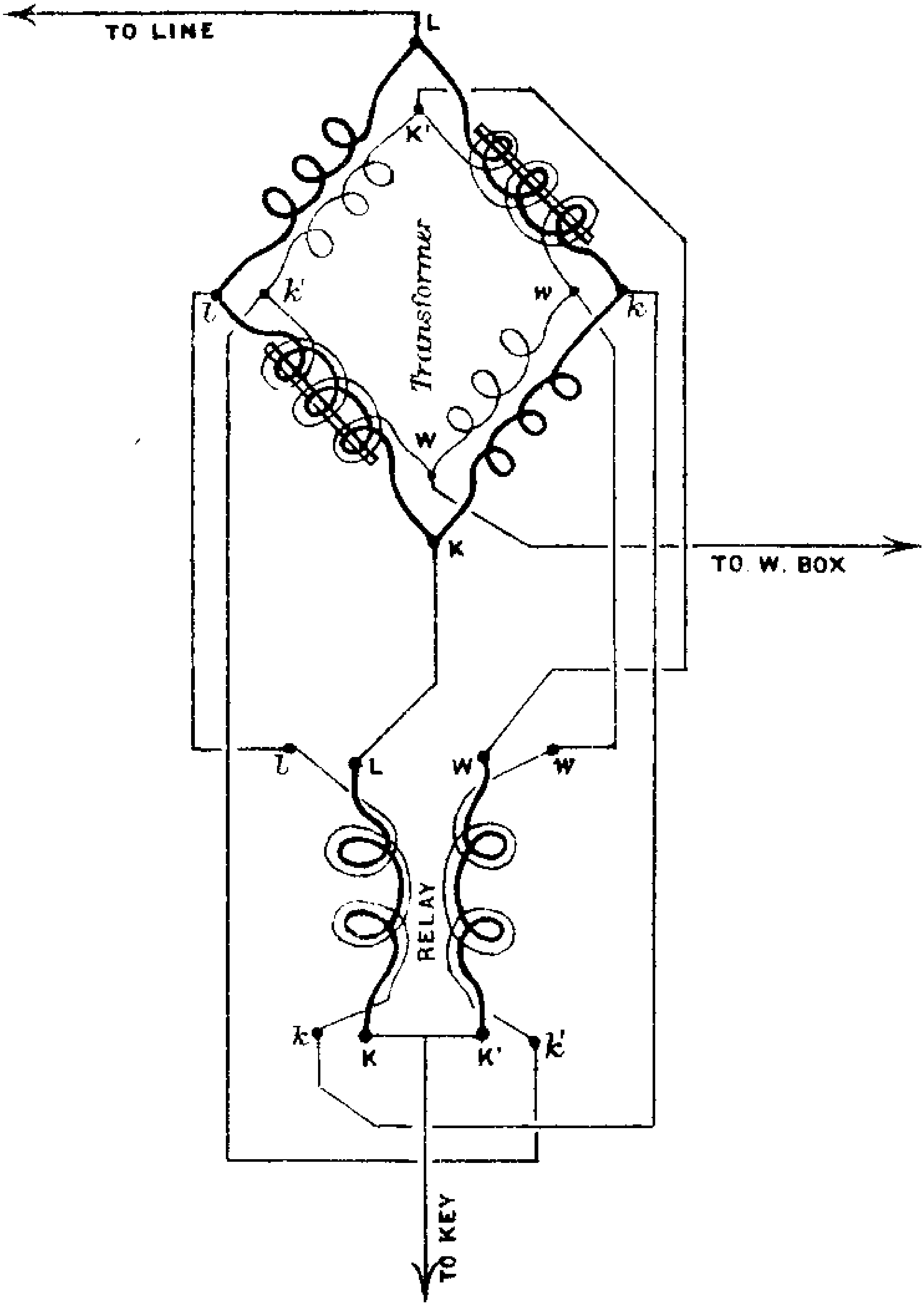

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FIG. XXIV

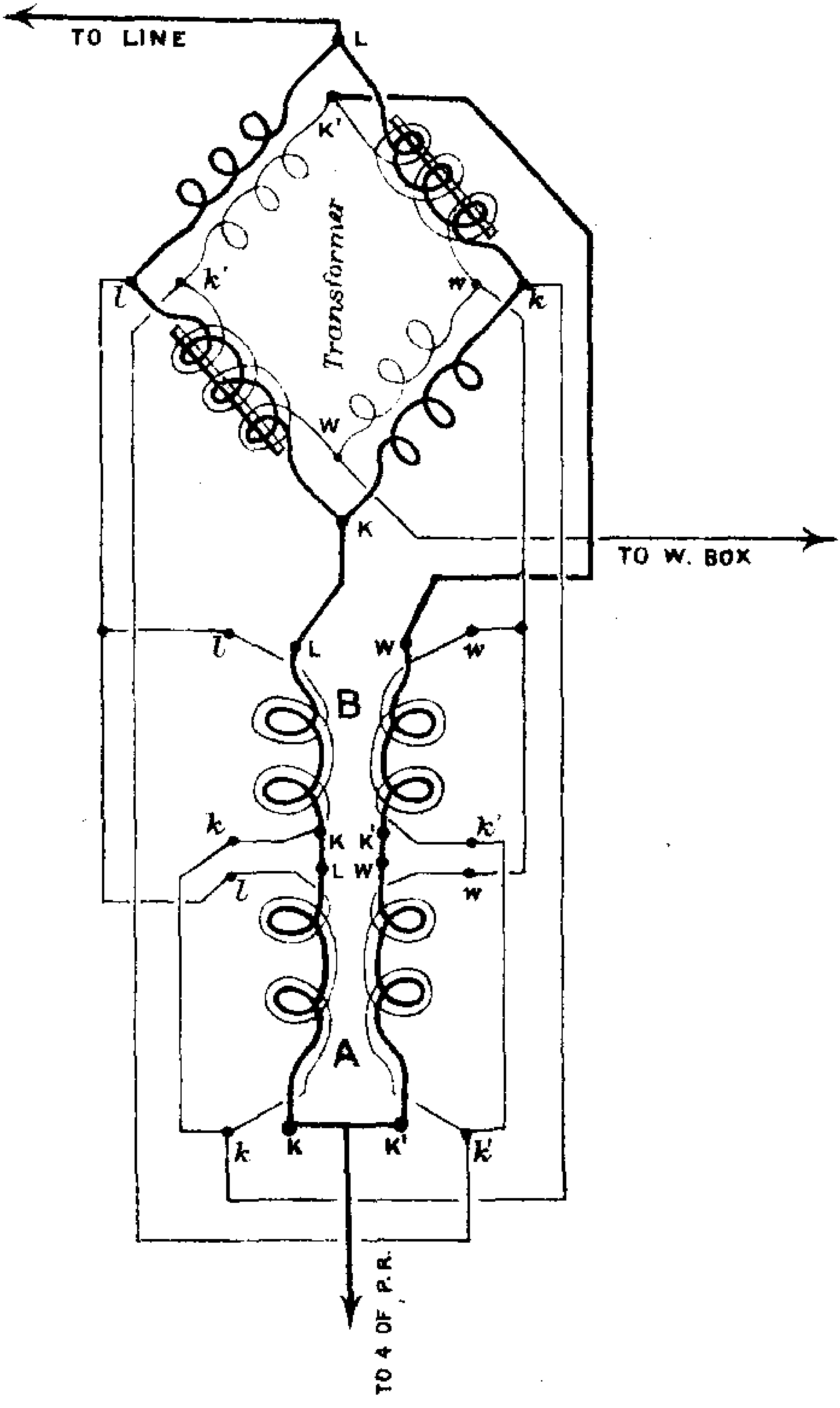
TO LINE
L
K'
Transformer
l
k'
w
k
W
K
TO W. BOX
l
L
W
w
B
k
K
K'
k'
L
W
l
w
A
k
K
K'
k'
TO 4 OF P.R.

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FIG. XXV

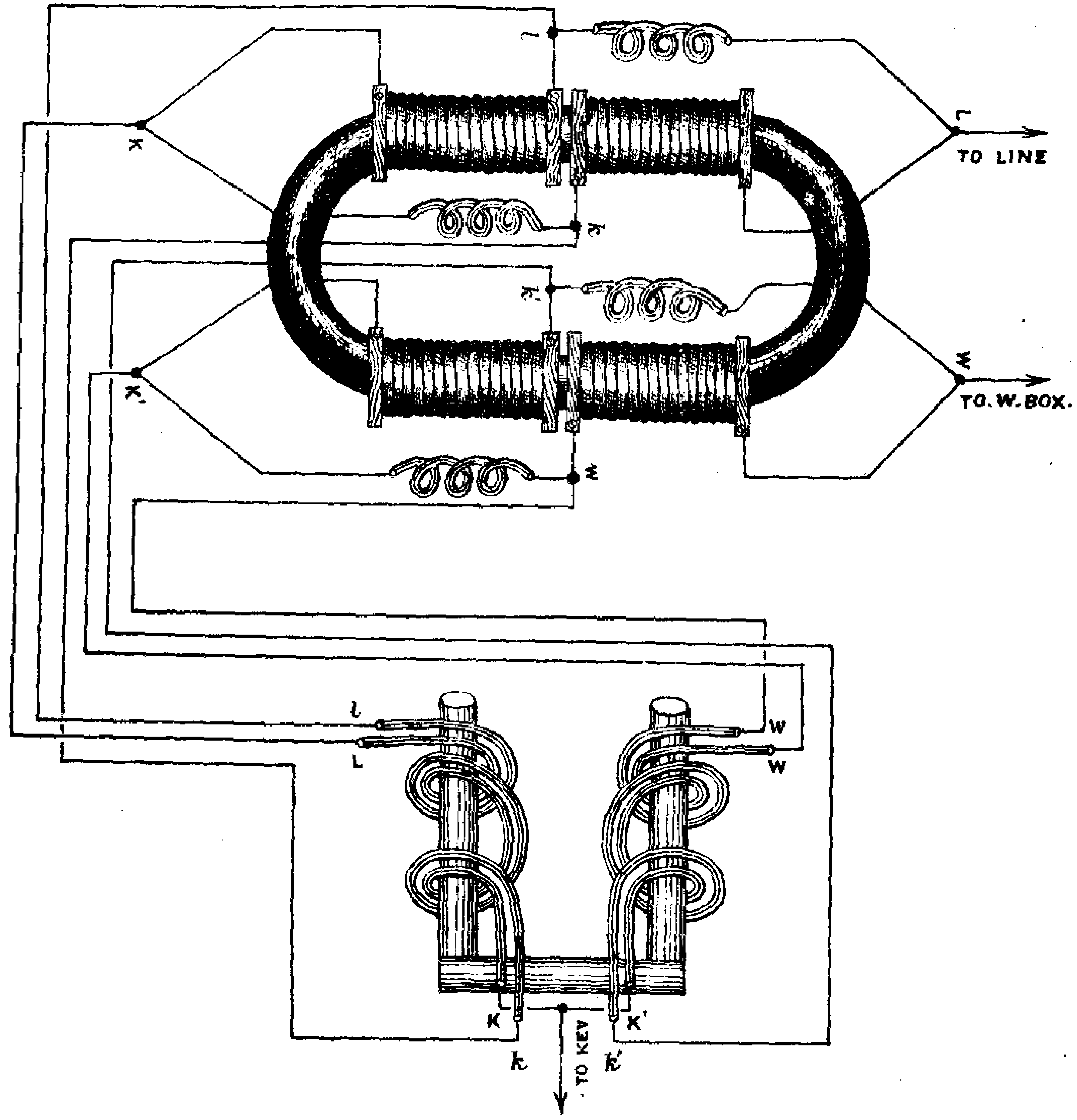

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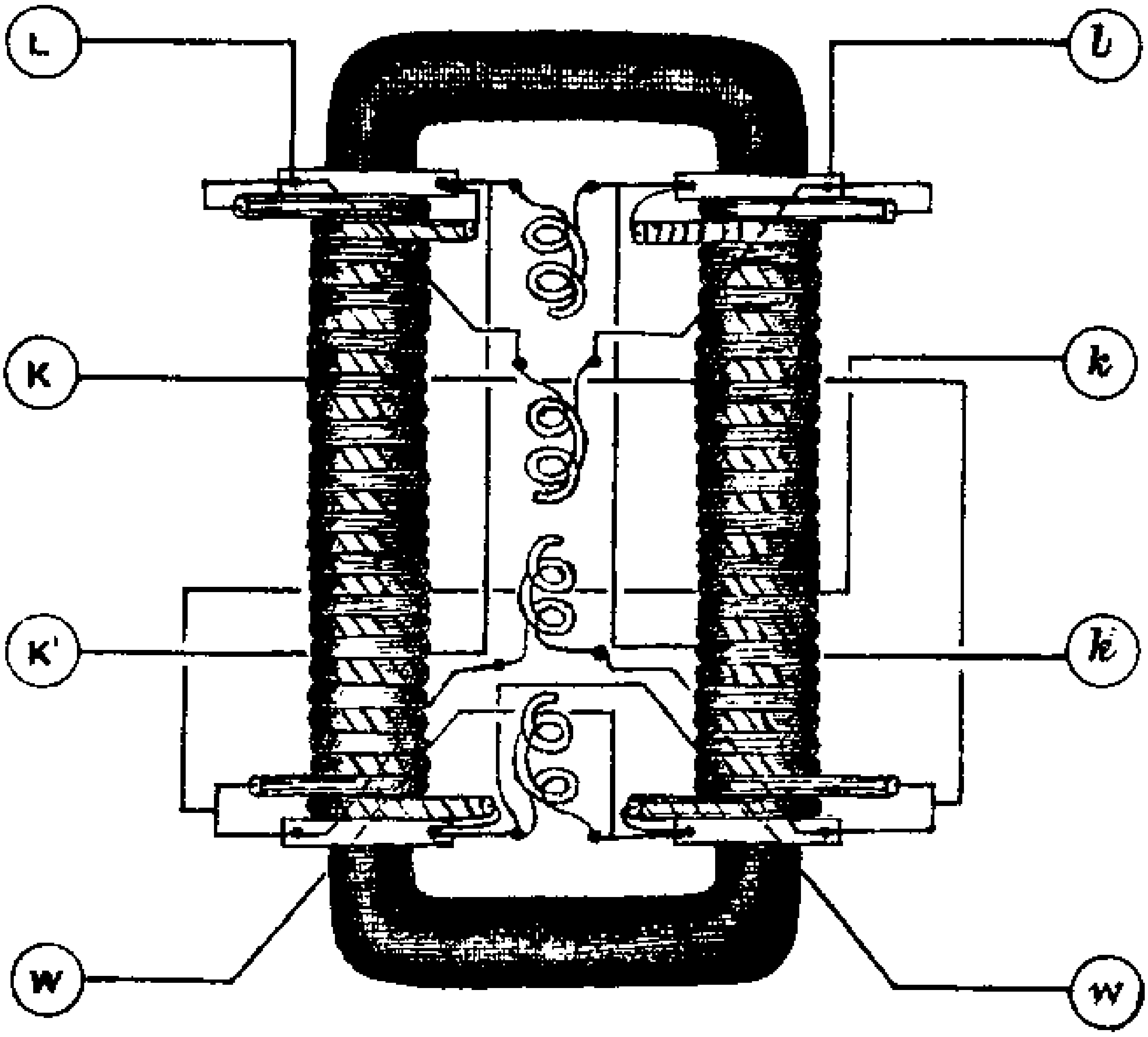
FIG. XXVI



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for the instrument, all that was necessary to be done when beats stuck was to reduce the resistance in the rheostat and increase when beats failed.

Fig. XXV represents the twin-transformer as originally issued from the store yard with this addition that a Standard Universal Relay is shown fitted up with it; but, the recently constructed instrument is made up in a more compact form with the inductive coils fitted above the non-inductive ones. (See Fig. XXVI.)

TESTING.

(*a*) TANGENT GALVANOMETER.

(27) *Description of the Tangent Galvanometer.*—Fig. XXVII represents a Tangent Galvanometer. It consists of two coils of copper wire, called the Thick (A) and the Thin (B) coils. In addition to these two coils four fixed resistances are inserted, two in the circuit of each coil. In the circuit of the A coil the fixed resistances are 20 and 200, and in that of the B coil 1,000 and 2,000. The A coil offers a resistance of about 1 ohm, and the B 100.

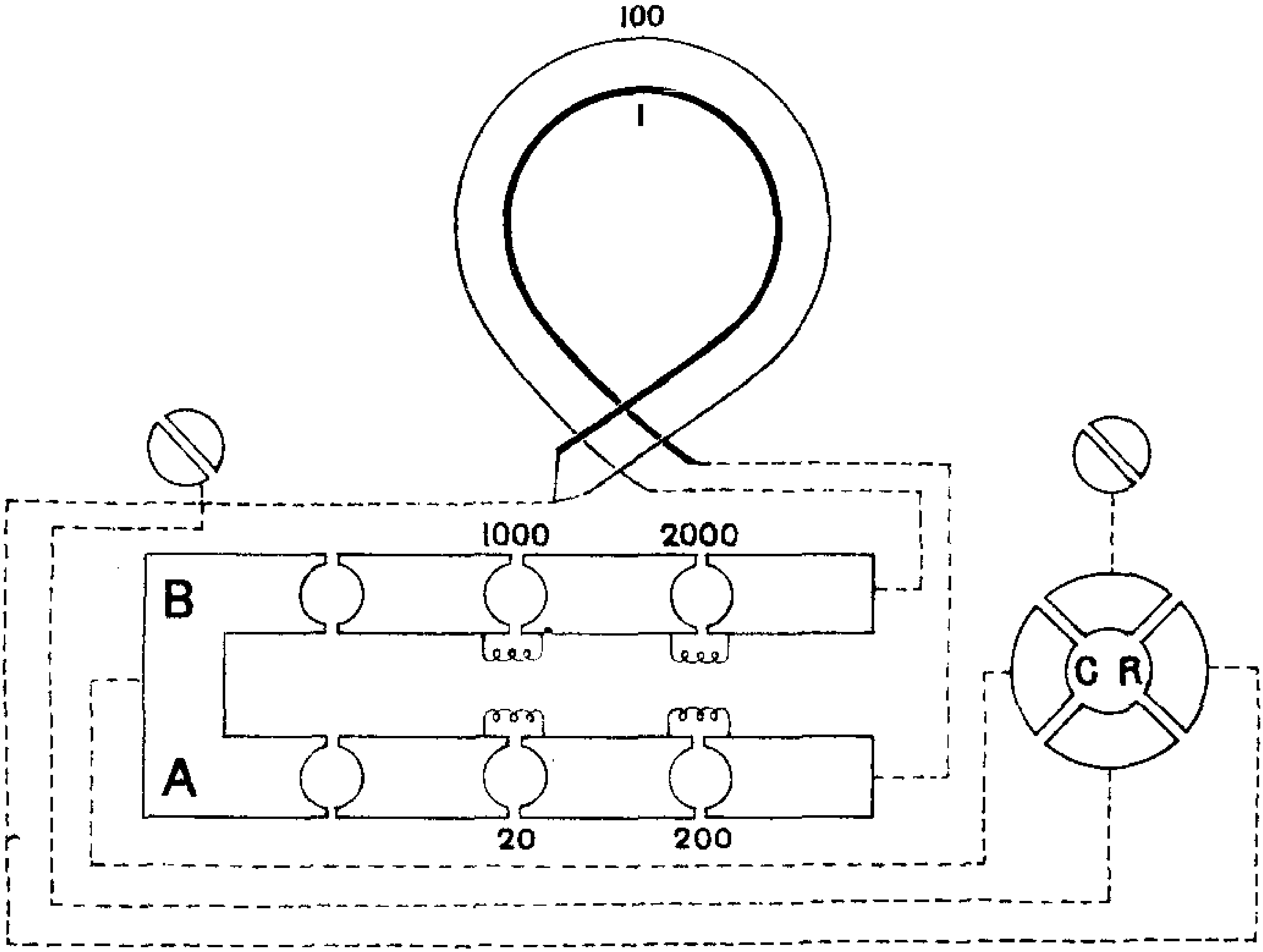
The graduated circular scale (not shown in the diagram) is fitted within the brass ring containing the coils and is at right angles to it. The needle (a small permanent magnet) is pivoted at the centre of this graduated scale. The needle is made one-sixth the diameter of the coil, or its length does not exceed the breadth of the brass ring containing the coils; the reason of this being to admit of the current passing through the coils having the greatest effect on the needle, the ends of which, in any position, lie within the space occupied by the breadth of the brass ring. An index or pointer (generally of aluminium) is fixed at right angles to the needle, by which deflections are read. The most reliable deflection with the Tangent Galvanometer is 45°, because the tangents increase very rapidly above this angle, and therefore there is the greatest possibility of an observation error being made. It must not, however, be supposed that deflections over 45° should not be accepted. Any deflection between 15° and 75° may be considered reliable.

(28) *Defects in the Tangent Galvanometer and how rectified.*—The following tabulated statement will clearly show you the necessary tests to be taken, and the methods adopted for removing defects which may exist in the Tangent Galvanometer :—

No.	Tests.	Results.	Defects, and how rectified.
1	Needle and Index.	(*a*) Should be free to swing and spin round on a strong current being sent through the coils ; (*b*) the pointer should move closely over the dial without touching it.	If the pointer touches the dial, it can easily be bent a little upwards till it just clears the dial.
2	The axis of the pointer.	Should be straight which is known by one end being placed to zero on one side; then the other end would also point to zero on the other side.	This will probably be due to the indicator or index being bent to the right or to the left. It should be straightened.
3	The axis of the Index.	Should be at right angles to the needle. This will be known by obtaining equal deflections, caused by the same current, on either side of zero point.	If the index is not at right angles to the needle, unscrew the screw which keeps the index and needle together; then file just a little of the index at its axis.

NOTE.—The deflection obtained through the thick coil depends on the internal resistance of the cell, and that through the thin coil (particularly through 2,000) on its electro-motive force.

FIG. XXVII



TANGENT GALVANOMETER

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No.	Tests.	Results.	Defects, and how rectified.
4	Magnetism of the needle.	Should make at least 7 oscillations in 10 seconds; but those needles which have aluminium dampers attached to them need not be *tested as above, but on being* deviated from the zero point should return to it gradually.	The magnetism of the needle is not constant. High temperature, direct rays of the sun, and strong currents, all tend to alter the *original magnetism of the needle*; it should be re-magnetized. The best or most convenient way of re-magnetizing a needle is to place the N. pole on the S. pole of a permanent horse-shoe magnet, and, of course, the S. pole on the N. pole of the magnet. Keep the magnet and needle thus connected for about 30 minutes, and the latter will be sufficiently re-magnetized.
5	The mechanical *state of* the pivot and agate cup of the needle.	(*a*) Should not make less than *15 oscillations in coming to rest*; (*b*) the pointer to return accurately to zero after the oscillations cease.	If the maximum number of oscillations cannot be obtained, it is an indication that the pivot is badly shaped or rusty or the cup dirty. Rust on the pivot is removed by the use of chalk and oil, and the cup can be cleaned with a match.
6	Sensibility of the galvanometer.	Through the thin coil, the standard cell should give at least a deflection of 5° through 2,000, 10° through 1,000, and 55° through no resistance (all plugs *in*). *Through the thick* coil and 200 ohms in circuit 4°.	If these deflections cannot be obtained, we conclude that one or more of the defects referred to above exist. Steps should be taken to rectify them.

NOTE.—The deflection obtained through the thick coil depends on the internal resistance of the cell, and that through the thin coil (particularly through 2,000) on its electro-motive force.

(29) *Explanation of the theory of the Tangent Galvanometer.*—The theory or principle of the Tangent Galvanometer is expressed thus :—

"*The strength of a current passing through the coil is proportional to the tangent of the angle of deflection.*"

Prior to conducting any tests, the coils of the Galvanometer must be set in the plane of the magnetic meridian, or the needle should point north and south, or better still, adjust the indicator (by turning the instrument round) till it points to zero.

Proof of the theory :—

Let 1 and 2 represent the plane of the magnetic meridian and 3 the point at which the needle N S is pivoted. Owing to a current passing through the coil the needle is deflected, forming the angle N 3 5, I shall term this angle a°. The needle is held in this position by two forces, one (6N) being the horizontal component of the earth's magnetism parallel to the magnetic meridian and the other (7N) the strength of the current in the coil, which may be considered as being at right angles to the magnetic meridian. The letter t represents the directive force of the earth's magnetism and X the force of the current, exerted on the N. pole of the magnet. Both the magnetism of the earth and the force of the current exert two distinct forces on the magnet which may be expressed thus (see Fig. XXVIII) :—

$$4\,X \text{ and } 4\,N = 5\,N \text{ and } 5\,t$$

but 4 X and 5 t being parallel, have no influence on the needle.

$$\therefore 4\,N = 5\,N$$

These are opposite forces, one of which tends to draw the N. pole of the magnet to the plane of the magnetic meridian, and the other to shift the N. pole further from it.

In this position of the needle we have

$$4\,N = 5\,N$$

$$\text{but } 4\,N = X.\cos a^\circ$$

$$\text{and } 5\,N = t \sin a^\circ$$

$$\therefore X \cos a^\circ = t \sin a^\circ$$

then dividing both sides by cos a° we have

$$X = \frac{t \sin a^\circ}{\cos a^\circ}$$

FIG. XXVIII

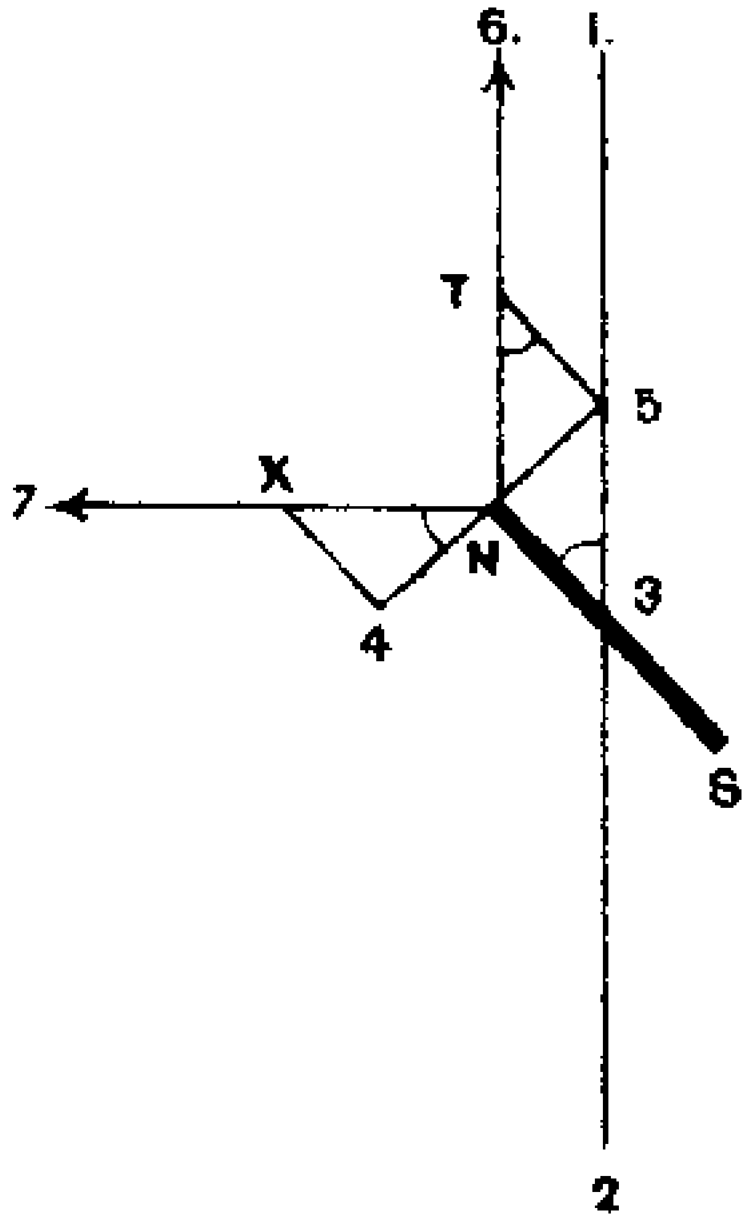
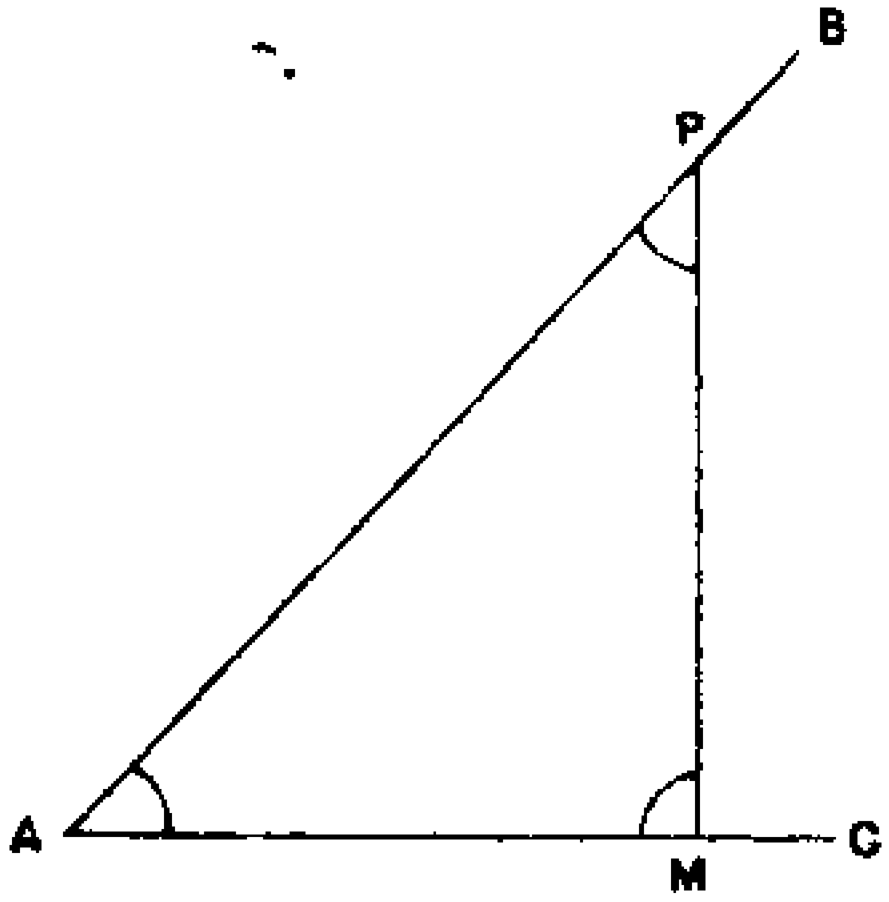


FIG. XXIX



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further, dividing both sides by t, we have

$$\frac{X}{t} = \frac{\sin a^\circ}{\cos a^\circ}$$

But $$\frac{\sin a^\circ}{\cos a^\circ} = \tan a^\circ$$

$$\therefore \frac{X}{t} = \tan a^\circ$$

multiplying both sides by t we have

$$X = t \tan a^\circ$$

or the strength of the current is proportional to the tangent of the angle of deflection.

(30) *Proof of the General Formula of the Tangent Galvanometer.*—The proof of the general formula of the Tangent Galvanometer when employed for comparative measurements only, from which other formulæ can be deduced, is expressed thus :

$$\frac{f^1 + g + w^1}{f + g + w} \times \frac{E}{E^1} = \frac{\tan a^\circ}{\tan a^{1\circ}}$$

According to Ohm's law we have

$$\therefore C = \frac{E}{R}$$

C represents current.
E „ electro-motive force.
R „ all the resistances in circuit.

Supposing we take one reading say C, and get the deflection $\tan a^\circ$, and by C^1 we get $\tan a^{1\circ}$, then we have

$$C = \tan a^\circ$$
$$\text{and } C^1 = \tan a^{1\circ}$$

To get the deflection a° we have had to employ an electro-motive force (E) and resistance (f), the current was passed through the Galvanometer (g) with an extra resistance (w) in circuit.

Then again by Ohm's law

$$C = \frac{E}{f + g + w}$$

$$\text{and } C^1 = \frac{E^1}{f^1 + g + w^1}$$

The current C^1 say was obtained from another battery of electro-motive force (E^1) and resistance (f^1), through the same Galvanometer (g) and another extra resistance (w^1).

Further, putting the equations together, we have

$$\frac{C}{C^1} = \frac{\dfrac{E}{f + g + w}}{\dfrac{E^1}{f^1 + g + w^1}}$$

and by inverting the fraction in the divisor and executing a multiplication, we get

$$\frac{C}{C^1} = \frac{E}{f + g + w} \times \frac{f^1 + g + w^1}{E^1} = \frac{E\,(f^1 + g + w^1)}{(f + g + w)E^1}$$

which may be written

$$\frac{C}{C^1} = \frac{f^1 + g + w^1}{f + g + w} \times \frac{E}{E^1}$$

$$\text{but} \quad \frac{C}{C^1} = \frac{\tan a^\circ}{\tan a^{1\circ}}$$

$$\therefore \frac{f^1 + g + w^1}{f + g + w} \times \frac{E}{E^1} = \frac{\tan a^\circ}{\tan a^{1\circ}}$$

This is the general formula of the Tangent Galvanometer which may be expressed in words thus: "*Currents are to one another as the resistances in the respective circuits inversely.*"

(31) *How Tan* 45° = 1.—The constant of a galvanometer has been defined as "*that current which produces unit deflection on that particular galvanometer.*" For instance, 45° on a Tangent Galvanometer.

Let BAC be an angle of 45.° Take any point P in AB and draw PM perpendicular to AC. (See Fig. XXIX.)

The three angles of a triangle being equal to two right angles, and since the angle P M A is a right angle, we have

$$90^\circ + 45^\circ + P = 180^\circ$$
$$\therefore 135^\circ + P = 180^\circ$$
$$\therefore P = 180^\circ - 135^\circ$$
$$\therefore P = 45^\circ$$

or the angle APM is an angle of 45° or half a right angle ; and the angle P A M is also half a right angle.

Further, the side opposite equal angles are in themselves equal.

∴ the side P M is equal to the side A M.

But the tangent of an angle is the ratio which the perpendicular bears to the base,

$$\therefore \text{Tan } A = \frac{\text{P M}}{\text{A M}}$$

but P M is equal to A M.

$$\therefore \text{Tan } A = \frac{\text{P M}}{\text{A M}} = 1$$
$$\therefore \text{Tan } 45^\circ = 1.$$

(32) *How to obtain the constant of the Tangent Galvanometer.*—To find the *constant* we must employ a certain strength of current which will give a deflection of about 45°. Supposing we

use 12 cells with an internal resistance of 240 ohms and obtain through the thin (B) coil, with 2,000 ohms in circuit, a deflection of 46°.

Then by Ohm's law we have

$$C = \frac{E}{R}$$

or in this case

$$C = \frac{12}{240 + 100 + 2000}$$

12 would represent the E. M. F. of 12 cells (taking 1 volt for each), 240 the internal resistance of the 12 cells, 100 the resistance of the thin (B) coil, and 2,000 the extra resistance inserted by removal of the plug from the hole marked 2,000 in the circuit of the thin (B) coil.

Then as above

$$C = \frac{12}{240 + 100 + 2000}$$

$$\therefore\ C = \frac{12}{2340}$$

$$\therefore\ C = 0{\cdot}005128 \quad \textit{ampères.}$$

Then to express the value of this current in *milliampères* we have to multiply 0·005128 *ampères* by 1000, which equals 5·128 *milliampères.* (A *milliampère* is one-thousandth of an *ampère.*)

From the above we see that a deflection of 46° is obtained from a current of 5·128 *milliampères ;* therefore a smaller quantity of current will be necessary to produce a deflection of 45°. Such being the case, to obtain the *constant,* we work by *Simple Rule of Three.*

$$46^\circ : 45^\circ :: 5{\cdot}128 : x$$
$$\therefore\ 46^\circ\ x = 45^\circ \times 5{\cdot}128$$
$$\therefore\ x = \frac{45^\circ \times 5{\cdot}128}{46^\circ}$$

On reference to the tangent table you will find that 45° = 1 and 46° = 1·035, therefore as above,

$$x = \frac{1 \times 5{\cdot}128}{1{\cdot}035}$$
$$\therefore\ x = \frac{5{\cdot}128}{1{\cdot}035}$$
$$\therefore\ x = 4{\cdot}954$$

The *constant* of the thin (B) coil, under the above conditions, you find to be 4·954.

(33) *Measurement of currents.*—The *constant* being thus known, the value of any current can be obtained as follows :—

Pass a current through the thin (B) coil with no external resistance in circuit (all plugs in) and note the deflection ; then, the tangent of the angle of this deflection multiplied by the *constant* will give you the value of the current in *milliampères*.

Thus supposing you obtain a deflection of 52°, and by referring to the tangent table you find that 52° = 1·28 ; then 1·28 × 4·954 (*constant*) = 6·34112, the value of the current.

(34) *How to test a Battery.*—The internal resistance (*f*) of a battery and its electro-motive force (E) can also be arrived at as follows :—

Take any Minotti cell or battery to be tested, connect one pole, say *Positive*, to one of the terminals of the instrument, and the *Negative* to the other. The tests for the internal resistance of such a battery should be conducted by aid of the thick (A) coil. Two distinct tests must be taken, one with all plugs in and the other with either 20 or 200 plug out. Experience teaches me that for the second deflection 20 ohms resistance should be placed in circuit for 4 cells or less and 200 for any above that number. To be accurate in these tests take the *right* and *left* deflections of each test by changing the direction of the current by aid of the current reverser attached to the instrument, as shown in Fig. XXVII, and then accept the mean of the tangents of these two deflections as the correct reading.

The formula for arriving at the internal resistance of a cell or battery from the two tests referred to above is written thus :—

$$f = \frac{\tan. a^{1°}}{\tan. a° - \tan. a^{1°}} \, w - g$$

f represents the internal resistance of a cell or battery (to be found).
$\tan. a^{1°}$,, the second or smaller deflection.
$\tan. a°$,, the first or larger deflection.
w ,, the resistance unplugged for the second deflection.
g ,, the resistance of the thick (A) coil which is generally about 1.

I will *first* proceed to prove that

$$f = \frac{\tan. a^{1°}}{\tan. a° - \tan. a^{1°}} \, w - g$$

By Ohm's law you have

$$C = \frac{E}{R}.$$

Then for the first test you have

$$C = \frac{E}{f + g}$$

and for the second

$$C^1 = \frac{E}{f + g + w}$$

Then putting the two together you have

$$\frac{C}{C^1} = \frac{\dfrac{E}{f+g}}{\dfrac{E}{f+g+w}}$$

$$\therefore \frac{C}{C^1} = \frac{E\ (f+g+w)}{E\ (f+g)}$$

but the same battery, hence the same electro-motive force, (E) being employed for both tests, $\frac{E}{E} = 1$ may be omitted.

$$\therefore \frac{C}{C^1} = \frac{f+g+w}{f+g}$$

$$\text{but } \frac{C}{C^1} = \frac{\tan.\ a^\circ}{\tan.\ a^{1\circ}}$$

$$\therefore \frac{\tan.\ a^\circ}{\tan.\ a^{1\circ}} = \frac{f+g+w}{f+g}$$

Then by multiplying both sides of the equation by $f + g$ you have

$$\frac{\tan.\ a^\circ\ (f+g)}{\tan.\ a^{1\circ}} = f+g+w$$

Further by multiplying both sides by tan. $a^{1\circ}$ you have

$\tan.\ a^\circ(f+g) = \tan.\ a^{1\circ}(f+g+w)$ which may be written

$(\tan.\ a^\circ) f + (\tan.\ a^\circ) g = (\tan.\ a^{1\circ}) f + (\tan.\ a^{1\circ}) g + (\tan.\ a^{1\circ}) w$

$\therefore\ (\tan.\ a^\circ)\ f - (\tan.\ a^{1\circ}) f = -(\tan.\ a^\circ)\ g + (\tan.\ a^{1\circ})\ g + (\tan.\ a^{1\circ})\ w$ which may be written

$f\,(\tan.\ a^\circ - \tan.\ a^{1\circ}) = -g\,(\tan.\ a^\circ - \tan.\ a^{1\circ}) + (\tan\ a^{1\circ})\ w$

or

$f\,(\tan.\ a^\circ - \tan.\ a^{1\circ}) = (\tan.\ a^{1\circ})\ w - g\,(\tan.\ a^\circ - \tan\ a^{1\circ}).$

Now dividing both sides by (tan. a° — tan. $a^{1\circ}$) you have

$$f = \frac{(\tan.\ a^{1\circ})\ w}{\tan.\ a^\circ - \tan.\ a^{1\circ}} - \frac{g\ (\tan.\ a^\circ - \tan.\ a^{1\circ})}{\tan.\ a^\circ - \tan.\ a^{1\circ}}$$

or

$$f = \frac{(\tan. a^{1^\circ})\, w}{\tan. a^\circ - \tan. a^{1^\circ}} - g$$

or

$$f = \frac{\tan. a^{1^\circ}}{\tan. a^\circ - \tan. a^{1^\circ}}\, w - g$$

By way of example ; supposing you test a battery of 12 cells and obtain the following results through the thick (A) coil,

1st test (all plugs in) tan. $a^\circ = 38$ deflection.

2nd test (200 ohms unplugged) tan. $a^{1^\circ} = 25$ deflection.

Then referring to the tangent table you find 38=0·7813 and 25=0·4663. Now all that you have to do to obtain the resistance of the battery is to subtract the 2nd from the 1st reading, note it ; then multiply the 2nd reading by the resistance unplugged and divide the result by the difference between the 1st and 2nd readings ; and lastly subtract 1, which is about the resistance of the thick (A) coil generally.

Thus :

```
0·7813                                 0·4663
0·4663                                    200
------                                -------
0·3150                                 93·2600
0·3150 )93·2600( 296·06
         6300
         ----
         30260
         28350
         -----
          19100
          18900
          -----
           20000
```

Then 296·06 — 1 = 295·06 is the resistance of the battery, and 295·06 ÷ 12 = 24·58, the average resistance per cell.

(35) *To compare or measure the E. M. F. of a battery.*—To compare the electro-motive force of a battery with that of a standard cell ; the resistance (*f*) of both the Battery and the Standard

Cell must first be found as shown above. Having tested the battery and the standard cell for resistance, take two readings only with the thin (B) coil.

(1) with the Battery and 2,000 ohms unplugged.

(2) with the Standard Cell and 1,000 ohms unplugged. These two readings being obtained you proceed to work by the following formula :—

$$E = \frac{\text{tan. } a^{\circ}}{\text{tan. } a^{1\circ}} \times \frac{f + g + w}{f^1 + g + w^1} \times E^1$$

I will *first* proceed to prove the above formula.

Supposing I represent by C the strength of current for the *first* reading and C^1 for the *second* ; then by Ohm's law

$$(1)\ C = \frac{E}{f + g + w}$$

$$(2)\ C^1 = \frac{E^1}{f^1 + g + w^1}$$

but $C = \text{tan. } a^{\circ}$ and $C^1 = \text{tan. } a^{1\circ}$

∴ (putting the two together)

$$\text{I have } \frac{\text{tan. } a^{\circ}}{\text{tan. } a^{1\circ}} = \frac{\dfrac{E}{f + g + w}}{\dfrac{E^1}{f^1 + g + w^1}}$$

$$\text{or } \frac{\text{tan. } a^{\circ}}{\text{tan. } a^{1\circ}} = \frac{E\,(f^1 + g + w^1)}{E^1\,(f + g + w)}$$

or the above may be written

$$\frac{\text{tan. } a^{\circ}}{\text{tan. } a^{1\circ}} = \frac{E}{E^1} \times \frac{f^1 + g + w^1}{f + g + w}$$

then by dividing both sides of the equation by

$$\frac{f^1 + g + w^1}{f + g + w}$$

$$\text{I have } \frac{\text{tan. } a^{\circ}}{\text{tan. } a^{1\circ}} \times \frac{f + g + w}{f^1 + g + w^1} = \frac{E}{E^1}$$

which may be written

$$\frac{E}{E^1} = \frac{\tan. a^{\circ}}{\tan. a^{1\circ}} \times \frac{f + g + w}{f^1 + g + w^1}$$

then multiplying both sides by E^1 I have

$$E = \frac{\tan. a^{\circ}}{\tan. a^{1\circ}} \times \frac{f + g + w}{f^1 + g + w^1} \times E^1$$

By way of example let me take a battery of 12 cells of 295 ohms and a standard cell of 20 ohms resistance ; then to compare the E. M. F. of the former with that of the latter I have to take two readings as stated above.

(1) tan. a° (with battery and 2000 ohms)
(2) tan. $a^{1\circ}$ (with standard cell and 1000 ohms)
Say

$$\tan. a^{\circ} = 50 \text{ and}$$
$$\tan. a^{1\circ} = 12$$

Then by referring to the tangent table I find 50 = 1·192 and 12 = 0·2125, therefore by formula

$$E = \frac{1{\cdot}192}{0{\cdot}2125} \times \frac{295 + 100 + 2000}{20 + 100 + 1000} \times 1$$

$$\therefore\ E = \frac{1{\cdot}192}{0{\cdot}2125} \times \frac{2395}{1120} \times 1$$

$$\therefore\ E = 5{\cdot}609 \times 2{\cdot}138 \times 1$$

$$\therefore\ E = 11{\cdot}99 \text{ about.}$$

The average E. M. F. per cell would therefore be 11·99 ÷ 12 = 0·99.

(36) *How to test low resistance cells.*—To find the internal resistance (f) of low resistance cells such as the Six-Block Leclanché, Fuller's Bichromate, etc., etc., employ the following formula :

$$f = \frac{R^1 - R\left(\dfrac{\tan. a^{\circ}}{\tan. a^{1\circ}}\right)}{\dfrac{\tan. a^{\circ}}{\tan. a^{1\circ}} - 1} - g$$

where

f = the internal resistance of the battery.
R^1 = resistance unplugged to obtain $a^{1\circ}$ for the second reading.
R = resistance unplugged to obtain a° for the first reading.
g = resistance of the thick coil of the Tangent Galvanometer.

Supposing you tested a battery of 6 Six-Block Leclanché cells and obtained the following results :—

For the first reading a° with a resistance (R) of 100 unplugged say you obtained a deflection of $56\frac{1}{2}^\circ$ and for the second reading $a^{1\circ}$ with a resistance (R^1) of 200 unplugged you got $38\frac{1}{2}^\circ$; then you proceed to work thus :—

(Referring to the Tangent table you find $56\frac{1}{2}^\circ = 1{\cdot}511$ and $38\frac{1}{2}^\circ = 0{\cdot}7954$)

$$\therefore f = \frac{R^1 - R\left(\dfrac{\tan.\ a^\circ}{\tan.\ a^{1\circ}}\right)}{\dfrac{\tan.\ a^\circ}{\tan.\ a^{1\circ}} - 1} - g$$

$$\therefore f = \frac{200 - 100\left(\dfrac{1{\cdot}511}{0{\cdot}7954}\right)}{\dfrac{1{\cdot}511}{0{\cdot}7954} - 1} - 1$$

$$\therefore f = \frac{200 - 100 \times 1{\cdot}89}{1{\cdot}89 - 1} - 1$$

$$\therefore f = \frac{200 - 189}{0{\cdot}89} - 1$$

$$\therefore f = \frac{11}{0{\cdot}89} - 1$$

$$\therefore f = 12{\cdot}36 - 1$$

$$\therefore f = 11{\cdot}36 \text{ (Resistance of the 6 cells)}$$

and

$$\frac{11{\cdot}36}{6} = 1{\cdot}89 \text{ (Resistance per cell).}$$

The E. M. F. may be compared and worked as explained before.

(37) *How to test external resistances.*—I will now proceed to show you how EXTERNAL RESISTANCES may be tested by aid of this instrument. Experience teaches me that a battery of 10 Minotti cells, the most, need be employed for testing with the *Thick* (*A*) coil and 2 to 3 cells, the least, with the *Thin* (*B*) coil. It must be remembered that high resistances should be tested with the *Thin* and low resistances with the *Thick* coil. Let me fix a limit, say 350 ohms or less, with the *Thick* coil and resistances above that number with the *Thin* coil.

Now, supposing you are given a SIÊMEN'S SOUNDER to test, then by reference to the resistance marked on the instrument you find that it has a resistance of about 30 ohms ; you therefore test it with the *Thick* coil.

A sounder of 30 ohms resistance is generally tested with a battery of 4 cells. You must first find the total resistance (f) of the 4 cells, as explained before. Say for your purpose the 4 cells offer a resistance of 60 ohms. Having obtained the resistance of the battery, you proceed as follows :—Take two readings and for sake of accuracy obtain the *mean* of the tangents of *right* and *left* deflections. (The *mean* is obtained by adding the tangents of *right* and *left* deflections and dividing the result by 2.)

1ST READING.—Make the following connections :—

Join A screw of the sounder to one terminal of the Galvanometer.

Join C screw of the sounder to COPPER of the Testing Battery.

Join ZINC of the Testing Battery to the other terminal of the Galvanometer.

Note the deflection, with all plugs in, in the *Thick* coil.

2ND READING.—Make the following connections :—

Join COPPER of the Testing Battery to one terminal of the Galvanometer.

Join ZINC of the Testing Battery to the other terminal of the Galvanometer.

Note the deflection with 20 ohms resistance unplugged in the *Thick* (*A*) coil.

The two readings having been obtained, you are in a position to work out the result by the following formula :

$$x = \frac{2nd \text{ Reading}}{1st \text{ Reading}} (f+g+w)-(f+g).$$

Supposing for the first reading you obtained a deflection of 45° and for the second 50°.

Then substituting the deflections, you have

$$x = \frac{\text{tan. } 50^\circ}{\text{tan. } 45^\circ} (f+g+w)-(f+g)$$

f = resistance of the Testing Battery, say 60 ohms.

g = resistance of the *Thick* (*A*) coil which is generally about 1.

w = resistance unplugged for 2nd reading, which is about 20.

Then substituting *figures* for *letters* in the foregoing formula, you have

$$x = \frac{\tan.50^\circ}{\tan.45^\circ}(60+1+20)-(60+1).$$

By reference to the *tangent table* it will be seen that

$$50^\circ = 1{\cdot}192 \text{ and}$$
$$45^\circ = 1{\cdot}000$$
$$\therefore x = \frac{1{\cdot}192}{1{\cdot}000}(60+1+20)-(60+1)$$
$$\therefore x = \frac{1{\cdot}192}{1{\cdot}000}(81)-(61)$$
$$\therefore x = \frac{1{\cdot}192 \times 81}{1{\cdot}000}-61$$
$$\therefore x = \frac{96{\cdot}552}{1{\cdot}000}-61$$
$$\therefore x = 96{\cdot}552-61$$
$$\therefore x = 35{\cdot}552 \text{ (the resistance of the Sounder).}$$

Any instrument can be tested for resistance as above, provided the proper battery power and coil of the Tangent Galvanometer are used to suit each case.

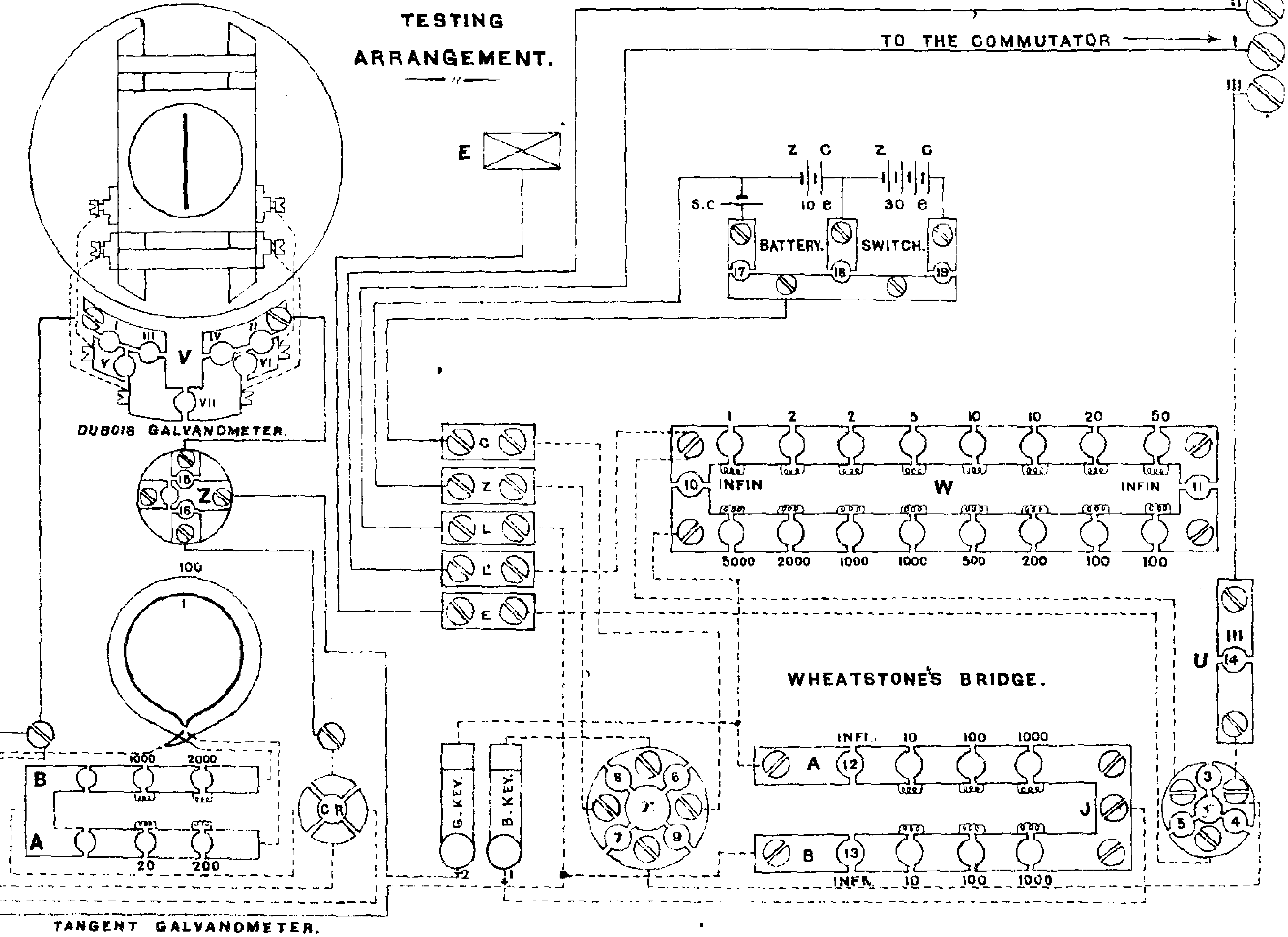
(B) WHEATSTONE BRIDGE.

The diagram, Fig. XXX, is generally called the **Testing Arrangement** by aid of which you are in a position to conduct such electrical tests as are necessary to keep in proper electrical condition or to trace and rectify such faults as may occur on the Line, in the Instruments and Batteries, etc., etc.

(38) *Description of the Testing Arrangement.*—It will be well for you first to understand the construction of the different parts of this Arrangement, and to be thoroughly acquainted with the connections before I attempt to explain how the various tests may be practically conducted.

To begin with let me give you a brief description of the W. Box.

FIG. XXX



TESTING ARRANGEMENT.

IMPERIAL
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(39) *The W. Box.*—This is generally known as the **Comparison Coil.** It consists of two rows of resistance coils, 8 on either side or 16 in all, having a total resistance of 10,000 ohms (varying from 1 to 5,000 ohms). By insertion or removal of plugs in the holes 10 and 11, you are in a position either to connect or disconnect the two sides, or rows of resistances. This box contains four terminal screws, but the two nearer the resistances 1 and 5,000 are generally employed; the external connections of which are as follow :—

The Screw nearer resistance 1 is joined to Screw II of the Commutator through the Connecting Bar L^1, and also to Switch *Y*.

NOTE.—*By insertion of a plug in 3 of Switch Y this screw is connected to the Battery Switch X, plug in 5 connects it to Earth through the Connecting Bar E, and plugs in 3 and 4 connect it both to the Battery Switch X and to Earth through the Connecting Bar E.*

The Screw nearer resistance 5,000 is joined to screw *A* of Branch Resistance *A*, and also to the *G Key.*

(40) *The Branch Resistances A and B.*—In the circuit of each of these two resistances are three coils of resistances 10, 100 and 1,000 ohms, respectively. By insertion of a plug in *12* the *A* Branch is brought into circuit, and a plug in *13* brings the *B* Branch in circuit. The three Screws generally employed are *A*, *B*, and *J*, the external connections are as follow :—

A is joined to *G Key* and also to that Screw of the **Comparison coil** nearer resistance 5,000.

NOTE.—*By means of the G Key, this Screw is connected to the Galvanometer Switch Z.*

B is joined to *I* of the Commutator through the Connecting Bar *L*, and also to those terminals of the Galvanometers which are not connected to the Galvanometer Switch *Z*.

J is joined to the Work Stop of *B Key*.

NOTE.—*By means of the B Key, this Screw is connected to the Battery Switch X.*

(41) *The two Keys* (*Battery and Galvanometer*).—The two keys employed with the BRIDGE are called *G* **Key** and *B* **Key**.

By working *G* **Key,** the Dubois Galvanometer (or any other Sensitive Galvanometer) is placed in connection with Screw *A* of Branch Resistance *A*, also to that screw of the **Comparison coil** nearer resistance 5,000, when a plug is inserted in *15* of Galvanometer Switch *Z*; and by shifting the plug to *16* the Tangent Galvanometer is brought into circuit.

By working *B* **Key** the Battery (Positive or Negative current as the case may be) is placed in connection with Screw *J* of the Branch Resistances.

(42) *The Connecting Bars.*—Five Connecting Bars are used with this Bridge which are *C*, *Z*, *L*, *L*^{1} and *E*. The internal connections are easily intelligible by reference to the diagram, and the external connections will be found further on.

(43) *The Switches employed with the Bridge.*—Three Switches are employed with the Bridge *X*, *Y* and *U*.

SWITCH *X* is an ordinary Current Reverser; by insertion of a plug in *6* the Connecting Bar *C* (*Positive*) is joined to the *B* **Key,** and by insertion of a plug in *7* the Connecting Bar *Z* (*Negative*) is joined to **Switch** *Y*. By inserting plugs in *8* and *9*, currents are reversed, *i.e.*, *Negative* is brought on to the *B* **Key** and *Positive* to **Switch** *Y*.

Switch *Y*. Plug in *3* connects the Battery to the Connecting Bar L^1, also to that Screw of the COMPARISON COIL nearer resistance 1. Plug in *4* connects the Battery to Earth. Plug in *5* connects the Connecting Bar L^1 and that Screw of the COMPARISON COIL nearer resistance 1 to Earth.

Switch *U*. By insertion of a Plug in *14*, Screw III of the Commutator is joined to **Switch** *Y*.

(44) *The External Connections of the Bridge.*—It will be seen by reference to the diagram (Fig. XXX) that the Bridge has *8* external connections as given below :—

(1) CONNECTING BAR C is joined to the **Battery Switch.**

(2) CONNECTING BAR Z is joined to **Zinc of the Testing Battery.**

(3) CONNECTING BAR L is joined to I of the **Commutator.**

(4) CONNECTING BAR L^1 is joined to II of the **Commutator.**

(5) CONNECTING BAR E is joined to **Earth**.

(6) SCREW III OF SWITCH U is joined to III of the **Commutator.**

(7) WORK STOP OF G KEY is joined to **Galvanometer Switch** Z.

(8) B OF BRANCH RESISTANCE B (*which is connected to Connecting Bar* L) is joined to that terminal of each of the Galvanometers which is not connected to **Switch** Z.

(45) *The Instruments employed with the Bridge:*—

(1) Sensitive Galvanometer (I have shown a Dubois Galvanometer in the Diagram).

(2) A Tangent Galvanometer.

(3) A Galvanometer Switch, and

(4) A Battery Switch.

The Sensitive Galvanometer is generally employed for Regular and Fault Tests, and occasionally when testing a battery by Poggendorff's method.

With the Tangent Galvanometer *Received* and *Outgoing* currents are measured.

By aid of the Galvanometer Switch *Z*, either the *Dubois* or the *Tangent Galvanometer* is brought into circuit, by insertion of a plug in *15* or *16*, respectively.

The Battery Switch enables you to connect 1 (standard cell) 10 or 40 cells to the CONNECTING BAR *C*, by insertion of a plug in *17*, *18* or *19*, respectively.

The COMMUTATOR helps you to connect 1, 2 or 3 wires as necessity arises, to the Testing Arrangement.

I will now endeavour to give you a brief description of the **Dubois Galvanometer,** such as is necessary for you to know.

(46) *Description of the Dubois Galvanometer.*—The **Dubois Galvanometer** contains two distinct systems of convolutions, which by aid of the **Commutator V** can either be *singly*, *successively* or *Parallelly* used. The two systems of convolutions are termed **Primary** and **Secondary.** To use the **Primary** system alone, you must insert plugs in I and IV of the **Commutator V** and to use the **Secondary** system alone, plugs must be inserted in II and III; then to use both the systems *successively*, you should insert plugs in I, II and VII; and lastly to use the two systems *parallelly*, you insert plugs in I, II, III and IV, or I, II, V, and VI.

Using the **Dubois Galvanometer** in the **Bridge,** the systems must be used parallel on account of it being the most sensitive arrangement; so that you should keep the plugs permanently in I, II, III and IV, or I, II, V, and VI. This instrument has two terminals which should be connected externally, thus: one terminal to that terminal of the **Tangent Galvanometer** which is joined to the junction connecting the **B Branch** to the **Connecting Bar L** of the **Bridge,** and the other terminal to the **Galvanometer Switch Z.**

(47) *How to measure the Current of the Testing Battery.*—Prior to conducting any external tests, the tester must first see that the **Bridge** itself tests perfect for **Conduction** and **Insulation**; he should, however, be certain that the current of the **Testing Battery** is sufficiently strong to cause a fairly good deflection on the **Tangent Galvanometer,** which is done by insertion of the following plugs *only* in the **Testing Arrangement**:—

(1) In 19 of the **Battery Switch.**

(2) In 6 of the **Current Reverser X.**

(3) All in the **B Branch** (*no plugs to be inserted in the A Branch*).

(4) In 16 of the **Galvanometer Switch Z.**

(5) In 10 of the **W Box** or **Comparison Coil** (*no need to remove remaining plugs*).

(6) In 3 of the **Switch Y,** and

(7) In 7 of the **Current Reverser X.**

Now press **B Key,** next **G Key,** and a deflection should be obtained from the **Testing Battery.**

NOTE.—*To obtain a deflection employ the* **B Coil** *of the* **Tangent Galvanometter** *by plugging up all the holes in the* **B Coil,** *and to test the* **Testing Battery** *for Resistance employ the* **A Coil** *as already explained.*

(48) *How to test the condition of the Bridge.*—The tester having thus satisfied himself that the **Testing Battery** is in order, he

should proceed to test the **Bridge** for **Conduction** and **Insulation**; (for sake of convenience the tests necessary are embodied in the following tabulated form.)

No. of Test.	Nature of Test.	Connection to be made.								Result.
		In A Branch (Plug 12).	In B Branch (Plug 13).	In W Box (Plug 11).	In X Branch.	In *Current Reverser X.*		In Switch Y.	In Galvanometer Switch Z.	
						For Pos.	For Neg.			
1	Conduction.	Plug all except Resistance 10.	Plug all except Resistance 10.	Plug all except 10 (Infin).	Join I and II at the Commutator.	Plug 6 and 7.	Plug 8 and 9.	Plug 3	Plug 15	Opposite branches being equal, no deflection should be observed on the Galvanometer.
2	Ditto ..	Ditto ..	Ditto ..	Unplug Resistance 1 also.	Ditto ..	Ditto..	Ditto..	Ditto..	Ditto..	A deflection of the needle should be observed indicating that W is too large.
3	Ditto ..	Ditto ..	Ditto ..	Ditto ..	Nsn. I and II at the Commutator.	Ditto..	Ditto..	Ditto..	Ditto..	A stronger deflection than the above should be observed on the opposite side showing X too large.
4	Ditto ..	Plug all except Resistance 1,000.	Plug all except Resistance 1,000.	Unplug 11 Infin. also.	Ditto ..	Ditto..	Ditto..	Ditto..	Ditto..	Opposite branches being equal, no deflection should be observed on the Galvanometer.
5	Insulation.	Plug all except Resistance 10.	Ditto ..	Unplug all except 11 (Infin.).	Ditto ..	Ditto..	Ditto..	Ditto..	Ditto..	Deflection of the needle should show X greater than $\frac{B}{A}$ W., *i.e.*, greater than one million.

Note. –The Dubois Galvanometer should be employed for the above tests. (Press B Key, then G Key.)

The formula of the **Bridge** is expressed thus :

$$x = \frac{B}{A} W.$$

Where x = the unknown resistance.

B = the resistance unplugged in the **B Branch** either 10, 100 or 1000.

A = the resistance unplugged in the **A Branch** either 10, 100 or 1000.

W = the resistance unplugged in the **W Box** or **Comparison Coil** from 1 to 10000.

(49) *How to test resistances varying from* 0·01 *to* 1000000 *ohms.*—Resistances from 0·01 ohms to one million ohms can be measured with the **Bridge**;

thus:—

Make A = 1000 (*Plug up Infin. 10 and 100 in the A Branch*).
„ B = 10 (*Plug up Infin. 100 and 1000 in the B Branch*).
„ W = 1 (*Plug up all except 10 (Infin.) and Res. 1 in W Box*).

NOTE:—(1) *In* **Current Reverser** *x, Plug 6 and 7 for Positive or 8 and 9 for Negative.*
(2) *In* **Switch Y**, *Plug 3.*
(3) *In* **Galvanometer Switch Z**, *Plug 15.*

(*Press* **B Key**, *then* **G Key**.)

Now referring to the above formula you have

$$x = \frac{B}{A} W$$

$$\therefore x = \frac{10}{1000} \times 1$$

$$\therefore x = \frac{10 \times 1}{1000}$$

$$\therefore x = \frac{10}{1000}$$

$$\therefore x = 0·01$$

By the above you see how a resistance of 0·01 ohms may be measured.

Then again;

Make A = 10 (*Plug up Infin. 100 and 1000 in the A Branch*).
„ B = 1000 (*Plug up Infin. 10 and 100 in the B Branch*).
„ W = 10000 (*Unplug all except Infin. in W Box*).

NOTE:—(1) *In* **Current Reverser** *x, Plug 6 and 7 for Positive or 8 and 9 for Negative.*

2) *In* **Switch Y,** *Plug 3.*

(3) *In* **Galvanometer Switch Z,** *Plug 15.*

(*Press* **B Key,** *then* **G Key.)**

Again referring to the above formula you have

$$x = \frac{B}{A} W$$

$$\therefore \quad x = \frac{1000}{10} \times 10000$$

$$\therefore \quad x = \frac{1000 \times 10000}{10}$$

$$\therefore \quad x = \frac{10000000}{10}$$

$\therefore \quad x = 1000000$ (*one million*).

You now see how resistances varying from 0·01 to 1000000 ohms may be measured with the Bridge.

You being now thoroughly acquainted with the connections of the Testing Arrangement, and having conducted the tests necessary to satisfy yourself that the **Bridge** is perfect for **Conduction** and **Insulation,** I will proceed to explain as simply as possible the meaning of the three terms used in connection with line testing :—

(50) *Actual Length, Gauge and Reduced Length.*

(1) **Actual Length,**

(2) **Gauge,** and

(3) **Reduced Length.**

Actual length means the exact wire mileage from the Testing Station to the Station which executes orders for test, or in other words the exact length of a wire within the Testing limits of a Testing Station.

Gauge means the number of the wire.

Reduced length of any particular section of wire is the quotient obtained by dividing the actual length of the section by the gauge of wire of that section; and then by adding the reduced lengths of the several sections together, the reduced length of the whole wire is obtained.

The example given below may tend to make the foregoing better understood :—

Ad.—Ag. Nos. 3, 4 and 14.

I. W. G.	Actual length of section.	Total actual length.	Reduced length of section.	Total reduced length.	Name of station.
(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)
24	11·82	11·82	0·4925	0·4925	Manauri.
24	12·00	23·82	0·5000	0·9925	Bharwari.
24	12·00	35·82	0·5000	1.4925	Sirathu.
24	16·00	51·82	0·66667	2·15917	Khaga.
24	9·00	60·82	0·37500	2·53417	Bharampur.
24	12·00	72·82	0·50000	3·03417	Fatehpur.
24	11·00	83·82	0·45833	3·49250	Malwa.
24	9·00	92·82	0·37500	3·86750	Mauhar.
24	15·00	107·82	0·62500	4·49250	Sarsaul.
24	12·00	119·82	0·50000	4·99250	Cawnpore, E. I. Ry.
24	14·00	133·82	0·58333	5·57583	Bhaupur.
24	14·00	147·82	0·58333	6·15916	Rura.
24	11·00	158·82	0·45833	6·61749	Jhinjhak.
24	13·00	171·82	0·54167	7·15916	Phaphund.
24	10·00	181·82	0·41667	7·57583	Achalda.
24	12·00	193·82	0·50000	8·07583	Bhartna.
24	13·00	206·82	0·54167	8·61750	Etawah.
24	10·00	216·82	0·41667	9·03417	Jaswantnagar.
24	12·00	228·82	0·50000	9·53417	Bhadan.
24	12·00	240·82	0·50000	10·03417	Shikohabad.
24	13·00	253·82	0·54167	10·57584	Firozabad.
24	10·00	263·82	0·41667	10·99251	Tundla.
24	14·85	278·67	0·61875	11·61126	Agra office.

To enable you to bear in mind how I have arrived at the foregoing figures I will ask you to remember, say

R = Reduced length.
A = Actual length.
G = Gauge.

You then have the word **RAG**. Now write the letters **R. A. G.** as in the following formula :—

$$R = \frac{A}{G} = \text{Reduced length.}$$

$$R \times G = A$$

$$\text{or} \quad A = R \times G = \text{actual length and}$$

$$G = \frac{A}{R} = \text{gauge.}$$

(51) *How to arrive at the resistance per mile of any wire.*—It will also be necessary for you to know that 252 ohms is taken as the **Standard Resistance per mile of wire** ; therefore, to know the *resistance per mile* of any wire you have simply to divide 252 by the gauge of that wire; thus, the Resistance per mile of No. 24 wire is 10·5 or $\frac{252}{24} = 10{\cdot}5$.

(52) *How to obtain the weight per mile of any gauge of wire.*—Now to obtain the weight per mile of any gauge of wire in *pounds* you have simply to multiply the number of the wire by 25 ; thus, the weight of No. 24 wire is 600 lbs. per mile or $24 \times 25 = 600$.

(53) *Rough Test Book.*—I will now take you to the **Rough Test Book** usually kept by the Testing Telegraph Masters, and explain its use. Each page of the Rough Test Book is folded into two lengthwise, the *left half* being reserved to record the tests con-

ducted, and the *right half* to work them out on. The particulars that have to be entered in this Book will be better understood by reference to a specimen of a page of that book given below :—

Regular Tests.

1st November 1897.

AD (Testing Station) **temp** $\frac{\text{Wet}}{\text{Dry}} = \frac{73}{77}$ Weather F.

(SPACE FOR RECORDING RESULTS.)			(SPACE FOR WORKING.)
Time 5.			
A G. 3.			
		Deflns.	
494 Crc	+ 3350	2 R.	
$\frac{1000}{1000}$	− 3450	5 R.	
$\frac{73}{75}$ Cdn	+ 2850	3 R.	
$\frac{1000}{1000}$	− 2950	4 R.	
Nsn	+ 8000		
$\frac{1000}{10}$	− 8000		

To explain the above I will take you to the **Testing Arrangement.** (Fig. XXX.)

(54) *Regular Testing.*—When preparing for **Regular Tests** the plugs to be inserted in the **Testing Arrangement** referred to here are 3, 4, 11, 12, 13, 15 and 19.

Plugs in 3 and 4 connect **L**^{1} or **II** of **Bridge** both to the Testing Battery and Earth.

Plug in 11 brings the **W Box** in circuit.
„ 12 „ **A Branch** „
„ 13 „ **B Branch** „
„ 15 „ **Dubois Galvanometer** in circuit.
and „ 19 „ **Testing Battery** in circuit.

Having got the **Testing Arrangement** ready to conduct tests, making the Branch Resistances A=B=1,000 (*i.e.*, all plugs in except 1,000 in each **A** and **B**) ; you call up the distant station, say for instance you test A.G. (Agra) No. 3 ; you give AG Crc (circuit) ; he replies by giving the resistance (say 494), marked on the Relay he is employing for the test. Having entered this in the Rough Test Book in the place shown in the specimen, you then bring the wire to be tested, by shifting a plug at the **Commutator**, to **L** or **I** of the **Bridge**—and next proceed thus :—

(1) **Before Test**—Press **G key** only and observe the deflection of the Galvanometer needle, say 2 degrees to the *right.*

(2) For the *Positive* result you insert plugs in 6 and 7 of the **Switch X,** now press **B key,** next **G key,** and plug or unplug resistances in the **W Box,** till the needle of the Galvanometer remains unaffected, when both the **B key** and **G key** are worked simultaneously. Note the result obtained by adding up the resistances in the **W Box** which remain unplugged : say you have 3350.

(3) For the *Negative* result you insert plugs in 8 and 9 of the **Switch** X and proceed as above. Note this result also : say you have 3450.

(4) **After Test** press the **G key** only, and observe the deflection of the Galvanometer needle, say 5 degrees to the *right.* From the above you find the *negative* result, higher than the *positive* ; this shows you that there is a *Positive Natural* current on the line ; *whichever result is lower that points to the kind of natural current on the line at the time of test.* Then, again, this *Positive Natural* current deflects the needle of the Galvanometer (depending on the

way it is connected in respect to the **Bridge**) to the *right;* therefore a *left* deflection would indicate a *Negative Natural* Current on the line; and the result with the *Negative* current would under that condition be lower than that obtained with the *Positive* current. Further (as already stated depending on the way in which the Galvanometer is connected) before balance is obtained, when testing with the *Positive* current, if the needle of the Galvanometer deflects to the *right,* on the keys being depressed, it indicates the resistance of **W** too large in comparison with the line under test, so that you must insert plugs in **W** to obtain balance; but if the needle deflects to the *left,* it indicates **W** too small in comparison with the line under test, and plugs must be removed from the **W** Box. With the *Negative* current, results reverse to the above will be obtained. Bearing the above in mind you proceed with the **Conduction Test**; having given A.G. Cdn (conduction) to which he replies by giving the temperature at the time of the test in the form of a fraction, thus $\frac{73}{75}$ meaning *Wet* 73, and *Dry* 75. You then proceed exactly as you did for the **Circuit Test,** only that the results now obtained will be lower, unless a fault exists on the line, then it will be about the same; say you now obtain, *Positive* 2850 and *Negative* 2950, and the deflections caused by the *Natural* current before and after the test 3 and 4 degrees respectively both to the right (R).

You now proceed with the Nsn (Insulation) test. Having given AG Nsn 3, and he replied by giving the state of the weather say F, you then obtain the results as follow:—

Keeping the Branch Resistances $\frac{B}{A} = \frac{1000}{1000}$, (testing with the *Positive* current,) if you find the needle deflects very much to the *left* indicating **W** too small you use the Branches $\frac{B}{A} = \frac{1000}{100}$, and if with the

Branches thus arranged, the needle still deflects to the *left*, then you use the Branches $\frac{B}{A} = \frac{1000}{10}$. In the first case the result would be $\frac{1000}{1000} \times 10000 = 10000$ ohms, or less, in the second $\frac{1000}{100} \times 10000 = 100000$ ohms, or less, and in the third $\frac{1000}{10} \times 10000 = 1000000$ ohms, or less.

Say the result obtained was 8000 with the Branches $\frac{B}{A} = \frac{1000}{10}$ or $\frac{1000}{10} \times 8000 = 800000$ ohms. It must be remembered that both the *Positive* and *Negative* results will not always be equal, but should ever the *Negative* be higher than the *Positive*, it would indicate a fault on the line.

(55) *Formulæ for Regular Testing.*—I will now proceed to show you under what conditions the results obtained for **Regular Tests** may be worked by each of the following methods :—

(1) Measured Values.

(2) Formulæ XXIV and XXV.

(3) Formulæ XXIVa and XXVa.

Supposing you tested **AG No. 3,** and obtained the following results :—

Example I.

494	**Crc**	+ 3350	2 R
		— 3450	5 R
$\frac{73}{75}$	**Cdn**	+ 2850	3 R
		— 2950	4 R
F	**Nsn**	+ 8000	
$\left(\frac{1000}{10}\right)$		— 8000	

You proceed first to find the *mean* of the above results :—

(W) **Crc** 3350
3450
2 | 6800
3400
(W) **Cdn** 2850
2950
2 | 5800
2900
(I) **Nsn** 8000
8000
2 | 16000
8000

The **Branch Resistances A** and **B** for both **Crc** and **Cdn** tests being equal, but for the **Nsn** test **A** = 10 and **B** = 1000 ; then by the formula of the **Bridge** $\frac{B}{A} = W$, in this case $\frac{1000}{10} \times 8000 = 800000$. Then :—

W = 3400
w = 2900
I = 800000

The next step would be to correct the resistance of the distant station relay employed for the **Crc** test. It must be remembered that the resistance of all relays are marked or rather corrected to a temperature of 80 degrees ; therefore for any temperature over 80 degrees the resistance is *higher* than that marked, and for any temperature below that standard, *lower*. Since it is my intention to avoid mathematical calculations as much as possible, my lectures being purely practical, I will ask you to accept the fact that since most of the relays employed for the circuit test are either 500 or 1000 ohms, that if I add 1 for each degree of temperature over 80 temperature of test. For relays of 1000 ohms resistance add 2. Then, again, I subtract 1 for 500 ohms and 2 for 1000 ohms relays for each degree of temperature below 80. The resistance of the relay given by **AG.** being 494, and temperature during test being 75 (*Dry*), I therefore find the corrected relay resistance thus :—

$$80 - 75 = 5$$
$$494 - 5 = 489$$

This is not all. It must also be remembered that relays are marked in **B. A.** units, and should you test with a **Bridge** in **Siemen's** units, you must convert the relay from **B. A.** to **Siemen's** units. Practically for every 100 **B. A.** units there is an increase of 5 for **Siemen's**, thus :—

B. A. units = 100
Siemen's = 105

The relay resistance given by AG. being 489 (corrected to temperature of test) then by *Simple Rule of Three* you have

$$100 : 105 :: 489 : x$$
$$x = \frac{105 \times 489}{100}$$
$$x = \frac{21 \times 489}{20}$$
$$x = 513{\cdot}45 \text{ or } 514$$

So that you can safely add 5 for each hundred of the Relay resistance. You therefore have AG. relay marked resistance 494, corrected resistance 489 and converted into **Siemen's** units 514.

The results finally obtained are :—

$\mathbf{W} = 3400$
$\mathbf{w} = 2900$
$\mathbf{I} = 800000$
$g = 514$

The following inequality should exist in the results :—

$$\mathbf{I} > \mathbf{W} > \mathrm{w}$$

and

$$\mathbf{W} - \mathrm{w} < g$$

Note :—*The Sign* > *means* **greater than** *and* < **less than**

You next find the difference between **W** and **w** or

$$\begin{array}{rcr} \mathbf{W} & = & 3400 \\ \mathrm{w} & = & \underline{2900} \\ & & 500 \end{array}$$

The *method adopted for working out the results obtained*, depends solely on the difference between **W** — **w** and the **Corrected Relay.**

(56) *Measured Values.*—In this case **W** — **w** = 500, and the **Corrected Relay** g = 514. Then since **W** — **w** = g approximately within 10 per cent. no corrections are necessary. You therefore proceed to work by **Measured Values.**

All you have to do is to find

(A) The Cdn per mile.

(B) The Nsn per mile.

To find the **Cdn** per mile resistance you have to divide the conduction resistance **w** by the **reduced length** of the wire, and to find the Nsn per mile you have to multiply the Insulation resistance **I** by the **actual length** of the wire.

Thus, for A G 3 you have

w = 2900
I = 800000

The **Cdn** per mile = 2900 ÷ 11·61 reduced length (see copy of **Gauge Book**) = 249·8 ohms

The Nsn per mile = 800000 × 278·67 actual length (*vide* copy of **Gauge Book**). Now to multiply 800000 by 278·67 entails much trouble, so that a simpler plan by Logarithms should be adopted thus :—

I 800000 = 5·9030900
278·68 = 2·4441058
ohms, 222400000 = $8·\overline{3471958}$

But 222400000 ohms must be converted into *megohms*, as the Nsn of the wire is expressed in *megohms* ; you therefore divide 222400000 by 1000000 (since one *megohm* equals one million ohms); you then have 222·4 *megohms* as the Insulation per mile of the wire and 249·8 ohms as the Conduction per mile.

(57) *Formulæ XXIV and XXV.*—I will take another example of the tests of A G No. 3, and explain why formulæ XXIV and XXV have been selected to arrive at the per mile Conduction and Insulation resistance :—

Example II.

626	**Crc**	+	3330	7L.
	$\frac{1000}{1000}$	–	3250	8L.
59 62	**Cdn**	+	2780	6L.
	$\frac{1000}{1000}$	–	2700	7L.
C	**Nsn**	+	1700	
	$\frac{1000}{100}$	–	1700	

You proceed to work as explained before.

(W) **Crc** 3330
3250
2 $\overline{6580}$
3290

$$\begin{array}{llr} (\mathrm{w}) & \mathbf{Cdn} & 2780 \\ & & \underline{2700} \\ & 2\,) & \underline{5480} \\ & & 2740 \end{array}$$

$$\begin{array}{llr} (\mathrm{I}) & \mathbf{Nsn} & 1700 \\ & & \underline{1700} \\ & 2\,) & \underline{3400} \\ & & 1700 \end{array}$$

You therefore have **Crc** 3290, **Cdn** 2740, and **Nsn** 17000 ohms or

W = 3290
w = 2740
I = 17000

Then (as explained before) you correct the *marked* relay resistance 626 and obtain 626 − (80 − 62) = 626 − 18 = 608 and 608 + 30 (Siemen's units) = 638.

The results finally obtained are :—

W = 3290
w = 2740
I = 17000
g = 638

Then, as explained before.

$$\begin{array}{lcr} \mathbf{W} & = & 3290 \\ \mathbf{w} & = & \underline{2740} \\ & & 550 \end{array}$$

In this case **W**—**w** 550 does not equal g 638, approximately within 10 per cent. you must therefore see whether the calculated relay does ; working it out by the following formula :—

$$\mathrm{I}\ \frac{(\mathbf{W}-\mathbf{w})}{\mathbf{I}-\mathbf{W}}.$$

I = 17000, **W—w** = 550 and **I** — **W** = 17000 — 3290 = 13710 ; the simplest and quickest way of working the above is by Logarithms (*please refer to the Mathematical Table of Logarithms*).

I = 17000 = 4·2304489
W—w = 550 = 2·7403627
6·9708116
I—**W** = 13710 = 4·1370374
681·9 = 2·8337742

You then obtain the calculated relay, say 682. Now see whether 682 equals *g* 638 approximately within 10 per cent. ; it does : so we proceed to work out the **Insulation** and **Conduction** *per mile* by the following formulæ :—

For **Nsn** . . . $i = \sqrt{I(I-w)}$
For **Cdn** . . . $L = 2\left\{I - \sqrt{(I-w)}\right\}$

Thus :—(by Logarithms.)

For Nsn.

I = 17000
w = 2740
14260
I = 17000 = 4·2304489
I—w 14260 = 4·1541195
8·3845684

Then to find the square root of 8·3845684 you simply divide by 2, thus :—

2 | 8·3845684
15570 = 4·1922842 = *i*

Now, as explained before, you find the Insulation *per mile* thus :—

i = 4·1922842
(Log. of actual length.) = 2·4441058
ohms 4329100 = 6·6363900

∴ 4329100 ÷ 1000000 = 4·3291 *megohms*

For Cdn.

From the above you find that the square root of **I** (**I** − w) equals 15570.

$\therefore \quad L = 2\ (I - 15570)$

but $\mathbf{I} = 17000$

$\therefore \quad L = 2\ (17000 - 15570)$

$\therefore \quad L = 2 \times 1430$

$\therefore \quad L = 2860$

Then, as explained before, you have 2860 ÷ 11·61 = 246·3 as the Conduction per mile.

If the results have to be worked by **Measured Values** or **Formulæ XXIV** and **XXV** then the line may be taken as uniform, *i.e.*, the **Resultant Fault** may be considered as coinciding with the **Centre** of Conduction resistance.

(58) *Formulæ XXIVa and XXVa, also XXIVb.*—Lastly I will take one more example of tests of A G No. 3, and explain why formulæ XXIV*a* and XXV*a* are selected to arrive at the *per mile* Conduction and Insulation resistance. The distance of the **Resultant Fault** from the Testing Station should be worked by formula XXIV*b*.

Example III.

495	**Crc**	+	2510	40 R
	$\frac{1000}{1000}$	−	2750	40 R
$\frac{56}{57}$	**Cdn**	+	2240	30 R
	$\frac{1000}{1000}$	−	2430	30 R
f	**Nsn**	+	480	
	$(\frac{1000}{100})$	−	560	

$$\begin{array}{llr} \textbf{(W)} & \textbf{Orc} & 2510 \\ & & \underline{2750} \\ & 2\,) & \underline{5260} \\ & & 2630 \end{array}$$

$$\begin{array}{llr} \textbf{(w)} & \textbf{Cdn} & 2260 \\ & & \underline{2430} \\ & 2\,) & \underline{4690} \\ & & 2345 \end{array}$$

$$\begin{array}{llr} \textbf{(I)} & \textbf{Nsn} & 480 \\ & & \underline{560} \\ & 2\,) & \underline{1040} \\ & & 520 \end{array}$$

$\mathbf{W} = 2630$
$\mathbf{w} = 2345$
$\mathbf{I} = 5200$

$g = 495 - (80 - 57) = 495 - 23 = 472$. (Relay corrected to the temperature of test.)

$472 + 24 = 496$. (Relay converted into Siemen's units.)

The results finally obtained are :—

$\mathbf{W} = 2630$
$\mathbf{w} = 2345$
$\mathbf{I} = 5200$
$g = 496$

$$\begin{array}{lcr} \mathbf{W} & = & 2630 \\ \mathbf{w} & = & \underline{2345} \\ & & 285 \end{array}$$

Then, since 285 does not equal g approximately within 10 per cent., the relay must be calculated by formula :—

$$\frac{\mathbf{I}\,(\mathbf{W} - \mathrm{w})}{\mathrm{I} - \mathbf{W}}$$

$I = 5200$, $W - w = 285$ and $I - W = 5200 - 2630 = 2570$.

Then by logarithms

$I = 5200 = 3{\cdot}7160033$

$\mathbf{W} - w\ 285 = 2{\cdot}4548449$

$6{\cdot}1708482$

$I - \mathbf{W}\ 2570 = 3{\cdot}4099331$

$576{\cdot}6 = 2{\cdot}7609151$

You then obtain the calculated relay resistance 576·6; and since it does not equal *g* 496 approximately within 10 per cent., you next have to obtain

(A) **Nsn** *per mile*
(B) **Cdn** *per mile*
(C) Distance of **R. F.** from the Testing Station.
(D) Position of **R. F.**

by the following formulæ.

(A) . . . $i = \sqrt{\frac{(I - W)\,g}{W - w}} \times I - w$ ....XXIV*a*

(B) . . . $L = I + \frac{(I - W)\,g}{W - w} - 2\,i$..................XXV*a*

(C) . . . $l = I - i$ ....XXIV*b*

(D) . . . $\mathbf{R.F.} = \frac{I - i}{L}$.

i = Corrected absolute **Nsn** of the whole line in *megohms.*

L = Corrected absolute **Cdn** of the whole line in ohms.

l = Real Conduction resistance in ohms from the testing station to R. F.

Then

$I - W = 5200 - 2630 = 2570$

$g = 496$

$W - w = 2630 - 2345 = 285.$

$I - w = 5200 - 2345 = 2855.$

∴ by logarithms,

(*i*) **Nsn** =

$$\begin{array}{rcl}
\mathbf{I-W} = 2570 &=& 3{\cdot}4099331\\
g = 496 &=& \underline{2{\cdot}6954817}\\
&& 6{\cdot}1054148\\
W-w = 285 &=& \underline{2{\cdot}4548449}\\
4472{\cdot}7 &=& 3{\cdot}6505659 = \frac{(I-W)\,g}{W-w}\\
\\
\mathbf{I}-w = 2855 &=& \underline{3{\cdot}4556061}\\
\textit{Square root } 2 &|& \underline{7{\cdot}1061760}\\
3573{\cdot}5 &=& 3{\cdot}5530880 = i\\
278{\cdot}68 &=& \underline{2{\cdot}4441058} = \textit{actual length of line.}\\
0{\cdot}9935 &=& 5{\cdot}9971938 = \mathbf{Nsn} \textit{ per mile.}
\end{array}$$

(L) **Cdn** =

$$\begin{array}{rcl}
\mathbf{I} &=& 5200\\
\frac{(I-W)g}{W-w} &=& \underline{4473} \text{ about}\\
&& 9673\\
2i = 3573{\cdot}5 \times 2 &=& \underline{7147}\\
&& 2526
\end{array}$$

Then 2526 = absolute conduction of the whole line.

∴ 2526 ÷ 11·61 = 217·6 (about) **Cdn** *per mile.*

(*l*) Real conduction resistance to **R. F.**

$$\begin{array}{rcl}
\mathbf{I} &=& 5200\\
i &=& \underline{3574} = l\\
&& 1626
\end{array}$$

∴ 1626 ÷ 217·6 (**Cdn** *per mile*) = 7·47 = Reduced distance to fault. Now referring to the **Gauge Book** you will find 7·47, under column (*e*), comes after 7·15 ; ∴ 7·47 — 7·15 = 0·32 : then 0·32 × 24 (Gauge of the section of wire on which the fault is localized) = 7·68 miles from Phaphund (column (*f*)) or 7·68 + 171·82 (actual length to Phaphund column (*c*)) = 179·5 miles from the testing station, or in this case from Allahabad.

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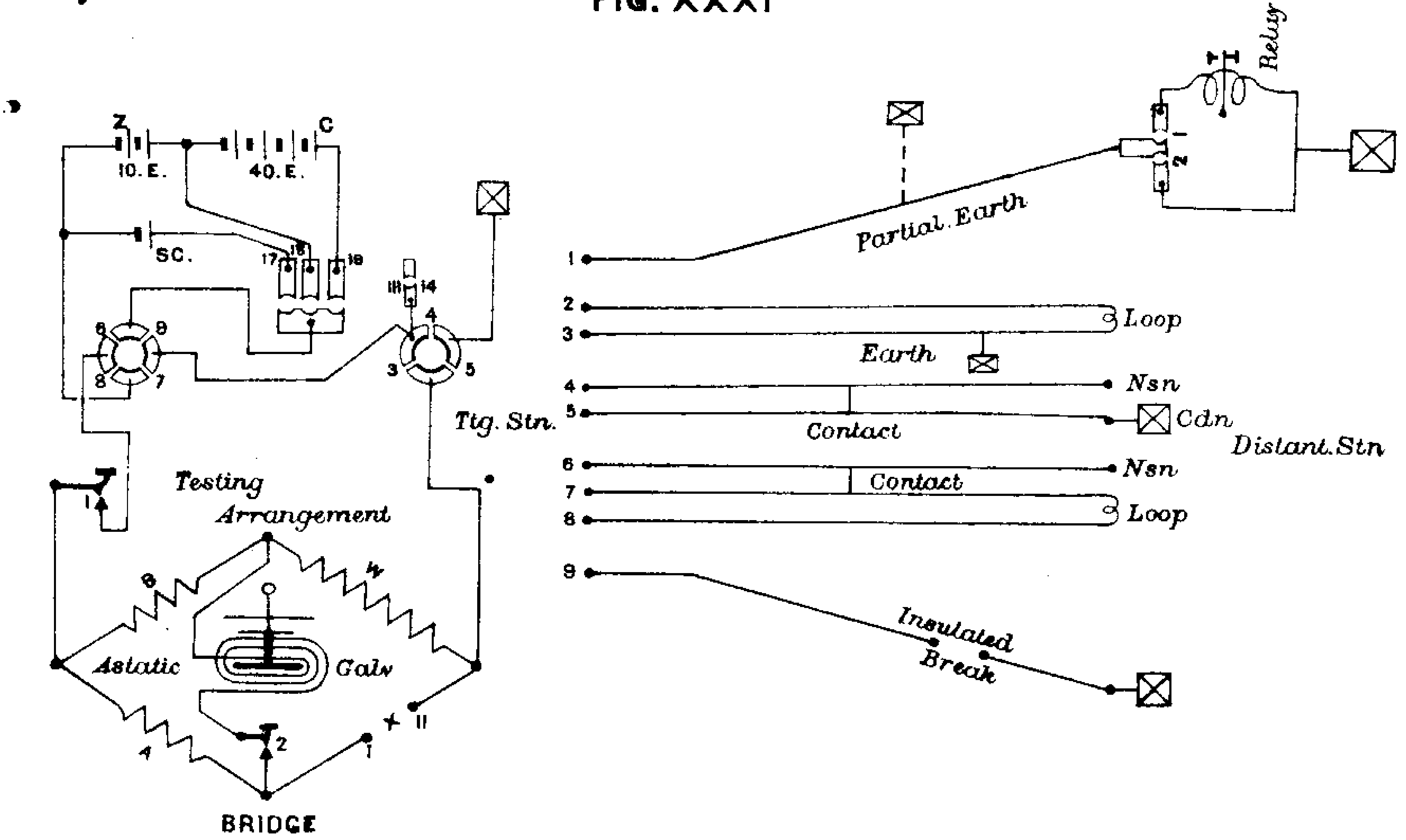
FIG. XXXI


Z
10. E.
40. E.
C
SC.
17
18
19
6
9
8
7
III
14
4
3
5
Tg. Stn.
Testing
Arrangement
1
8
4
Astatic
Galv
4
2
1
II
BRIDGE
Relay
1
2
Partial. Earth
1
2
3
Loop
Earth
4
Nsn
5
Cdn
Contact
Distant. Stn
6
Nsn
7
Contact
8
Loop
9
Insulated
Break

(59) *Position of the Resultant Fault.*—You then proceed to find out the position of the R. F. in respect to the whole line by the following formula :—

$$\frac{l}{L} = \frac{I - i}{L}$$

l (as shown above) = 1626
L (Do.) = 2526

$$\therefore \; 2526)\ 1626{\cdot}0\ ({\cdot}6437$$

$$\begin{array}{r} 15156 \\ \hline 11040 \\ 10104 \\ \hline 9360 \\ 7578 \\ \hline 17820 \\ 17682 \\ \hline \end{array}$$

$$\therefore \; \frac{l}{L} = 0{\cdot}6437$$

(60) *Fault Testing.*—To enable you to have a clear idea of the methods adopted for the localization of the various **Faults,** I have embodied them in a *Tabulated* **Form,** by reference to which (APPENDIX B) the more familiar and usually employed tests will, I hope, be understood without much trouble.

By aid of examples, I shall endeavour to show you how the **distance to fault** may be arrived at. (See Fig. XXXI.)

(61) *Partial Earth on a single wire.*—When there is *Partial* Earth on any wire the distant station can be worked though not so well as when the line is perfect. You are, therefore, in a position to conduct the three tests **Crc, Cdn and Nsn**. (I will take for granted that you, having followed me closely, are thoroughly acquainted with the manner of conducting these tests, so I will pass on.)

Supposing you obtain :—

Example I.

(W)	**Crc**	*(mean)*	2170
(w)	**Cdn**	„	1780
(I)	**Nsn**	„	11750
(g)	**Relay**		536.

You proceed to work the above by formula :—

$$x = \mathbf{I} - \frac{\sqrt{(\mathbf{I}-\mathbf{W})\,g}}{\mathbf{W}-w} \times \mathbf{I}-w.$$

Now

$$\begin{array}{rcllcl}
\mathbf{I} & = & 11750 & & & \\
\mathbf{I}-\mathbf{W} & = & 11750-2170 & = & 9580 \\
g & = & 536 & & & \\
\mathbf{W}-w & = & 2170-1780 & = & 390 \\
\mathbf{I}-w & = & 11750-1780 & = & 9970
\end{array}$$

Then by *Logarithms*

$$\begin{array}{rclcl}
\mathbf{I}-\mathbf{W} & = & 9580 & = & 3{\cdot}9813655 \\
g & = & 536 & = & \underline{2{\cdot}7291648} \\
 & & & & 6{\cdot}7105303 \\
\mathbf{W}-w & = & 390 & = & \underline{2{\cdot}5910646} \\
 & & 13166 & = & 4{\cdot}1194657 = \dfrac{(\mathbf{I}-\mathbf{W})\,g}{\mathbf{W}-w} \\
 & & & & \\
\mathbf{I}-w & = & 9970 & = & \underline{3{\cdot}9986952} \\
 & & \textit{square root} & 2 \mid & 8{\cdot}1181609 \\
 & & 11200 & = & 4{\cdot}0590804 = i \\
\therefore\ x \text{ or } \mathbf{I}-i & & & = & 11750-11200 = 550
\end{array}$$

Again by formula :

$$\mathbf{L} = \mathbf{I} + \frac{(\mathbf{I}-\mathbf{W})\,g}{\mathbf{W}-w} - 2\,i$$

the **corrected Absolute Conduction** in *ohms* of the wire will be known.

From the above you have

$$I = 11750$$

$$\frac{(I - W)g}{W - w} = 13166$$

$$2i = 11200 \times 2 = 22400.$$

$$\therefore 11750 + 13166 - 22400 = 2516.$$

You therefore have 2516 as the **absolute conduction in** *ohms* of the wire under test.

Now to find the **Cdn per mile** of the wire you have to divide 2516 by 10·07 say (the *resistance per mile* of the wire); thus

$$\frac{2516}{10{\cdot}07} = 249{\cdot}8$$

But

$$I - i = 550$$

$$\therefore \frac{550}{249{\cdot}8} = 2{\cdot}201$$

You therefore have 2·201 as the *reduced distance* to fault.

Then, by referring to the following extract from the **Gauge Book,** you trace at once the *faulty* section.

Gauge of wire.	Actual length of Section.	Total actual length.	Reduced length of Section.	Total reduced length.	Faulty Section.
A	B	C	D	E	F
31	10·0	65·971	0·32258	2·19689	Pahara.
31	9·0	75·471	0·30615	2·50334	Chunar.

From the above it will be observed that the *reduced distance* to fault being 2·201, the fault exists between Pahara and Chunar.

To find the **actual distance** to fault from the Testing Station you proceed thus :—

(See under column E of extract from **Gauge Book** given above.)

2·201 — 2·196 = 0·005

The gauge of wire being 31

∴ 0·005 × 31 = 0·155.

0·155 is therefore the **distance to fault** from Pahara ; and Pahara being 65·971 miles from the Testing Station (*vide* column **C**) ∴ the **distance to fault** from the Testing Station = 65·971 + 0·155 = 66·126.

(62) *Dead Earth on a single wire.*—

Example II.

Supposing for this test you get

Cdn to fault + 590
— 520

Find the mean, thus

590 + 520 ÷ 2 = 555.

Therefore 555 equals the *conduction resistance* to fault ; then by dividing 555 by 252 (*Cdn per mile* known from a previous test) you have 2·202 as the *reduced distance* to fault.

Then, as already explained, and by reference to the extracts from **Gauge Book** given above, you trace at once the *faulty* section.

Therefore

Distance to fault =(2·202 — 2·196) 31 + 65·971 = 66·157 miles from the Testing Station.

(63) *Dead or partial earth when two wires are available for test.*—

Example III.

Supposing you arrive at the following results :—

Loop.	+ 4240
	— 4240
Locln.	+ 2340
	— 2340

Then, working the above by formulæ shown in *Appendix B* under column 9, you have

$x - y \div 2 = \mathbf{R\ F.}$

$x = 4240$

$y = 2340$

$$\therefore \quad \frac{x - y}{2} = \frac{4240 - 2340}{2} = 950.$$

Then, supposing the *reduced lengths* of the two wires included in the loop test are 6·56 and 9·79, you add them together.

$$\begin{array}{r} 6{\cdot}56 \\ 9{\cdot}79 \\ \hline 16{\cdot}35 \end{array}$$

Since

$x \div \mathbf{R\ L}$ (both wires) $= \mathbf{P\ M}$

You have

$4240 \div 16{\cdot}35 = 259{\cdot}3.$

Then again

$\text{R F} \div \text{P M} = \text{R D}$

$\therefore \quad 950 \div 259{\cdot}3 = 3{\cdot}66.$

Having obtained 3·66 as the *reduced distance* to fault as already explained ; by referring to the extract from **Gauge Book** given below, you trace at once the *faulty* section.

Gauge of wire.	Actual length of Section.	Total Actual length.	Reduced length of Section.	Total reduced length.	Faulty Section.
A	B	C	D	E	F
36	13·0	123·301	0·36·11	3·54958	Unchehra.
36	8·75	132·051	0·24305	3·79163	Maihar.

∴ **Distance to fault** $= (3{\cdot}66 - 3{\cdot}55)\ 36 + 123{\cdot}3 = 127{\cdot}26$ miles from the Testing Station.

(64) *T. on two wires when only two wires are available.*—

Example IV.

Supposing you obtain the following results :—

$$\textbf{Cdn} \quad \left.\begin{matrix} +\ 2890 \\ -\ 2450 \end{matrix}\right\} \ \textit{mean}\ 2670$$

$$\textbf{Locln.} \quad \left.\begin{matrix} +\ 1550 \\ -\ 1110 \end{matrix}\right\} \ \textit{mean}\ 1330$$

Then *vide* formulæ under column 9 of *Appendix B* you have

$$x + y \div 2 = \mathrm{R\ F}$$

But

$$x = 2670$$

$$y = 1330$$

$$\therefore \mathrm{R\ F} = 2670 + 1330 \div 2 = 2000.$$

Further

$$x \div \mathrm{R\ L}\ (\textit{of wire to I of } \textbf{Bridge}) = \mathrm{P\ M}.$$

Then say the R L = 10·07

$$\therefore 2670 \div 10{\cdot}07 = 265{\cdot}1$$

Lastly

R F ÷ P M = R D

∴ 2000 ÷ 265·1 = 7·544.

Then find the distance to fault from the Testing Station as already explained.

By reference to the extract from the **Gauge Book** given below you trace at once the *faulty* section.

Gauge of wire.	Actual length of Section.	Total actual length.	Reduced length of Section.	Total reduced length.	Faulty Section.
A	B	C	D	E	F
3×18	0·142	172·867	0·00263	6·42620	
24	87·462	260·329	3·64425	10·07045	

∴ **Distance to fault** = (7·544 — 6·426) 24 + 172·867 = 199·699 miles from the Testing Station.

(65) *T. on two wires when another good wire is available.*—

Example V.

Supposing you arrive at the following results :—

Loop + 4050
— 4050
Locln. + 2850
— 2850

Then *vide* formulæ under column 9 of the *Tabulated Form* you have

$x - y \div 2 =$ R F

But

$x = 4050$

$y = 2850$

$\therefore \quad R\,F = 4050 - 2850 \div 2 = 600$

Further

$x \div$ R L (*of wires to I & II of Bridge*) = P M.

Then say the R L of both wires = 6·56 + 9·79 = 16 35

$\therefore \quad 4050 \div 16{\cdot}35 = 247{\cdot}7$

Lastly R F ÷ P M = R D.

$\therefore \quad 600 \div 248$ (say) $= 2{\cdot}41$.

Then find the **distance to fault** as explained above. The following is an extract from the **Gauge Book** by reference to which the *faulty* section will be known.—

Gauge of wire.	Actual length of Section.	Total actual length.	Reduced length of Section.	Total reduced length.	Faulty Section.
A	B	C	D	E	F
36	3·00	74·801	0·08333	2·20237	Tickoreah.
36	10·25	85 051	0·28472	2·48709	Majhgawan.

∴ **Distance to fault** = (2·41 − 2·20) 36 + 74·8 = 82·36 miles from the Testing Station.

(66) *Insulated Break.*—

Example VI.

Supposing you obtain the following results :—

Then *vide* formula under column 9 of *Appendix B* you have—

Nsn to fault + 5800

$\frac{1000}{100} - 5800$

Therefore the absolute insulation of the broken wire would be 58000.

Then say from previous test i = 47000.

∴ **Distance to fault** =

$$\frac{47000 \times 246}{58000} \text{ (length of wire)}$$

Then by *logarithms* (being easier to work) you have

$$\begin{array}{rcl} 47000 & = & 4{\cdot}6720979 \\ 246 & = & \underline{2{\cdot}3909351} \\ & & 7{\cdot}0630330 \\ 58000 & = & \underline{4{\cdot}7634280} \\ 199{\cdot}3 & = & \underline{2{\cdot}2996050} \end{array}$$

∴ **Distance to fault** = 199·3 miles from the Testing Station.

This test is seldom or never accurate.

ADDITIONAL NOTES.

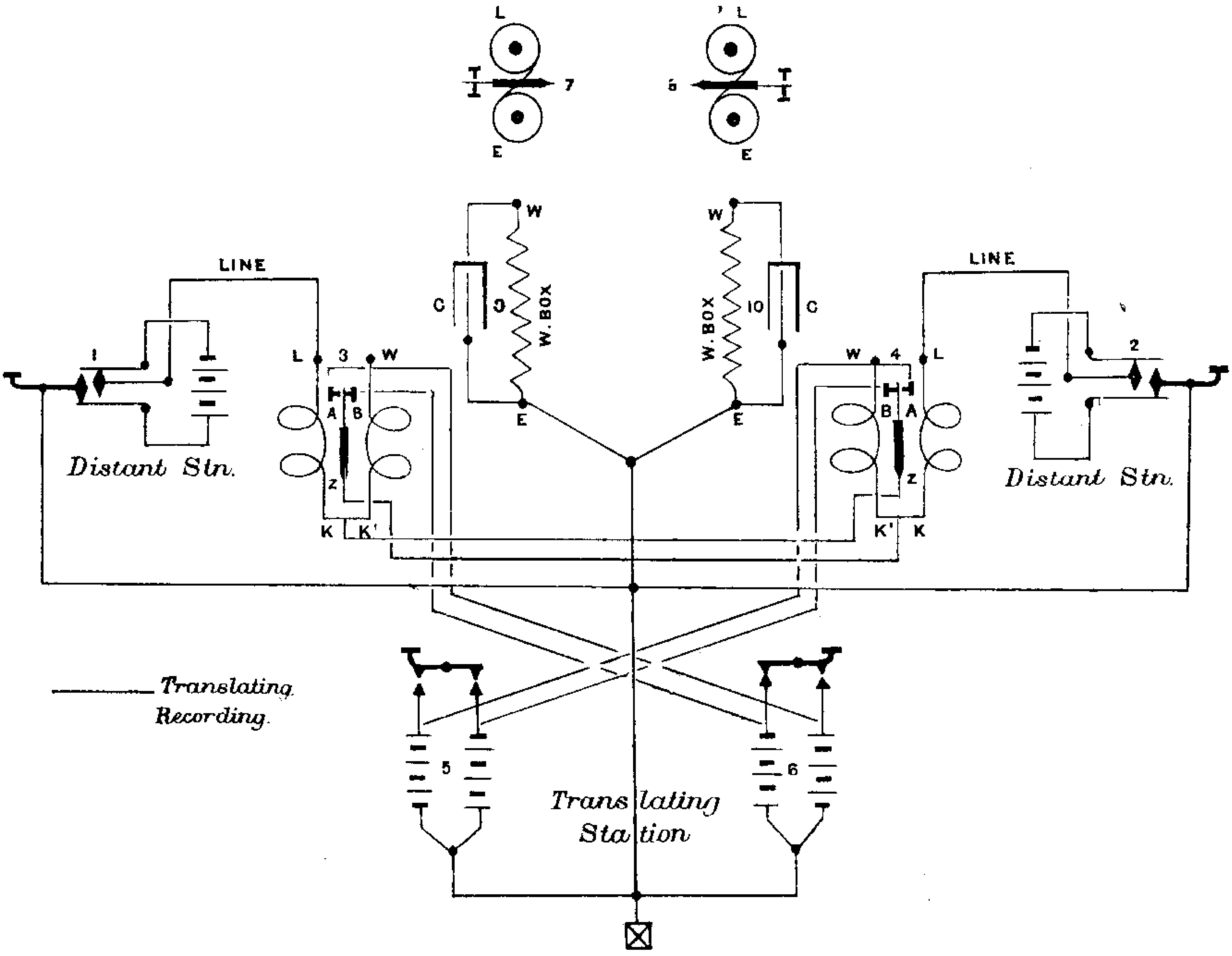
(a) *Double Current Differential Duplex Translation.*—On a beat being given on Key No. 1, Translating Relay No. 3 works, which latter in its turn starts a positive current from Battery No. 6 and passes it on to the junction K K^1 of Translating Relay No. 4, where it splits, half going to Earth through the Distant Station Relay and battery, working the Distant Relay, and the other half through Recording Relay No. 7 and W. Box No. 10, working Recording Relay No. 7, and hence the Sounder; or I might say on Key No. 1 being worked the following Instruments at the Translating Station work simultaneously :—

(*a*) Translating Relay No. 3.
(*b*) Recording Relay No. 7.
(*c*) Sounder (not shown in the sketch) in connection with Recording Relay No. 7.

When Key No 2 is worked, it causes Translating Relay No. 4 to work, which in its turn starts a positive current from Battery No. 5 and passes it on to the junction K K^1 of Translating Relay No. 3, where it splits, half going to Earth through the Distant Station Relay and battery working the Distant Station Relay, and the other half through Recording Relay No. 8 and W. Box No. 9, working Recording Relay No. 8, and hence the Sounder; or I may say on Key No. 2 being worked the following Instruments at the Translating Station work simultaneously :—

(*a*) Translating Relay No. 4.
(*b*) Recording Relay No. 8.
(*c*) Sounder (not shown in the sketch) in connection with Recording Relay No. 8.

Double Current Differential Duplex Translation



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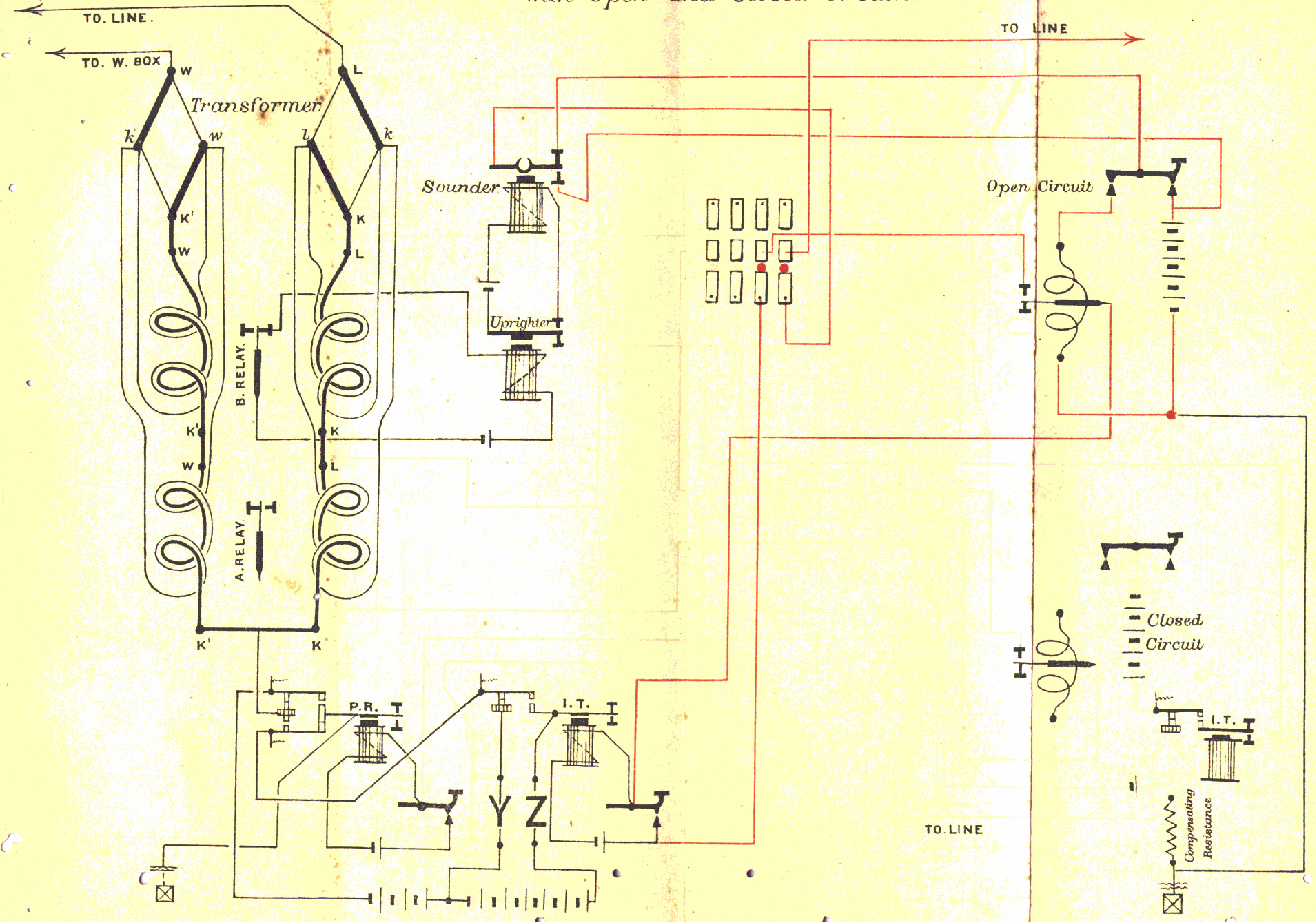
Translation-Quadruplex with Open and Closed Circuits.



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When both Keys Nos. 1 and 2 are worked simultaneously (which means Duplex) both Translating Relays Nos. 3 and 4 and Recording Relays Nos. 7 and 8, and hence the Sounders in connection with the latter work. The Translating Relays send out currents on either side opposing the Distant currents, hence by the passage of the home currents through K^1 W of Distant Relays, the Distant Relays, and hence the Sounders connected to them work.

(b) *Translation—Quadruplex with Open and Closed Circuits.*—The B Sounder at the Translating Station translates the signals of the Distant B side of Quadruplex on to the Open Circuit and the A Relay, the signals of the Distant A side of Quadruplex on to the Closed Circuit by closing the Circuit of the Closed Circuit side Increment Transmitter battery. On the Closed Circuit side Increment Transmitter being worked, all Instruments, with the exception of the Home (Translating) Relay, in Circuit work, as explained in para. 14.

The Relay on the Open Circuit at the Translating Station translates the Distant Open Circuit signals on to the Distant B side of Quadruplex by closing the Circuit of the Increment Transmitter battery on the Quadruplex Circuit and thereby working it.

The Relay on the Closed Circuit at the Translating Station translates the Distant Closed Circuit signals on to the Distant A side of Quadruplex by closing the Circuit of the Pole Reverser battery and thereby working it.

Open and Closed Circuits may thus be joined to either side of a Quadruplex Circuit.

APPENDIX A.

Table of Natural Tangents for every Quarter Degree.

ANGLE.		Tan.	ANGLE.		Tan.	ANGLE.		Tan.	ANGLE.		Tan.	ANGLE.		Tan.
Deg.	Mts.		Deg.	Mts.		Deg.	Mts.		Deg.	Mts.		Deg.	Mts.	
0	0	0·0000	9	0	0·1584	18	0	0·3249	27	0	0·5095	36	0	0·7265
	15	0·0044		15	0·1629		15	0·3297		15	0·5150		15	0·7332
	30	0·0087		30	0·1673		30	0·3346		30	0·5205		30	0·7399
	45	0·0131		45	0·1718		45	0·3394		45	0·5261		45	0·7467
1	0	0·0174	10	0	0·1763	19	0	0·3443	28	0	0·5317	37	0	0·7535
	15	0·0218		15	0·1808		15	0·3492		15	0·5373		15	0·7604
	30	0·0262		30	0·1853		30	0·3541		30	0·5429		30	0·7673
	45	0·0305		45	0·1898		45	0·3590		45	0·5486		45	0·7743
2	0	0·0349	11	0	0·1944	20	0	0·3639	29	0	0·5543	38	0	0·7813
	15	0·0393		15	0·1989		15	0·3689		15	0·5600		15	0·7883
	30	0·0437		30	0·2034		30	0·3739		30	0·5658		30	0·7954
	45	0·0480		45	0·2080		45	0·3789		45	0·5715		45	0·8026
3	0	0·0524	12	0	0·2125	21	0	0·3839	30	0	0·5773	39	0	0·8098
	15	0·0568		15	0·2171		15	0·3889		15	0·5832		15	0·8170
	30	0·0612		30	0·2217		30	0·3939		30	0·5890		30	0·8243
	45	0·0655		45	0·2263		45	0·3987		45	0·5949		45	0·8317
4	0	0·0699	13	0	0·2309	22	0	0·4040	31	0	0·6008	40	0	0·8391
	15	0·0743		15	0·2355		15	0·4091		15	0·6068		15	0·8465
	30	0·0787		30	0·2401		30	0·4142		30	0·6128		30	0·8541
	45	0·0831		45	0·2447		45	0·4193		45	0·6188		45	0·8616
5	0	0·0875	14	0	0·2493	23	0	0·4245	32	0	0·6249	41	0	0·8693
	15	0·0919		15	0·2539		15	0·4296		15	0·6309		15	0·8769
	30	0·0963		30	0·2586		30	0·4348		30	0·6371		30	0·8847
	45	0·1007		45	0·2633		45	0·4400		45	0·6432		45	0·8925
6	0	0·1051	15	0	0·2679	24	0	0·4452	33	0	0·6494	42	0	0·9004
	15	0·1095		15	0·2726		15	0·4504		15	0·6556		15	0·9083
	30	0·1139		30	0·2773		30	9·4557		30	0·6619		30	0·9163
	45	0·1183		45	0·2820		45	0·4610		45	0·6682		45	0·9244
7	0	0·1228	16	0	0·2867	25	0	0·4663	34	0	0·6745	43	0	0·9325
	15	0·1272		15	0·2915		15	0·4716		15	0·6809		15	0·9407
	30	0·1316		30	0·2962		30	0·4769		30	0·6873		30	0·9489
	45	0·1361		45	0·3009		45	0·4823		45	0·6937		45	0·9573
8	0	0·1405	17	0	0·3057	26	0	0·4877	35	0	0·7002	44	0	0·9657
	15	0·1450		15	0·3105		15	0·4931		15	0·7067		15	0·9741
	30	0·1494		30	0·3153		30	0·4986		30	0·7133		30	0·9827
	45	0·1540		45	0·3201		45	0·5040		45	0·7199		45	0·9913

Table of Natural Tangents for every Quarter Degree.—(concld.)

ANGLE.		Tan.	ANGLE.		Tan.	ANGLE.		Tan.	ANGLE.		Tan.	ANGLE.		Tan.
Deg.	Mts.		Deg.	Mts.		Deg.	Mts.		Deg.	Mts.		Deg.	Mts.	
45	0	1·000	54	0	1·376	63	0	1·963	72	0	3·078	81	0	6·314
	15	1·009		15	1·389		15	1·984		15	3·124		15	6·497
	30	1·0 8		30	1·402		30	2·006		30	3·171		30	6·691
	45	1·026		45	1·415		45	2·028		45	3·220		45	6·897
46	0	1·035	55	0	1·428	64	0	2·050	73	0	3·271	82	0	7·115
	15	1·045		15	1·441		15	2·07[illegible]		15	3·323		15	7·348
	30	1·054		30	1·455		30	2·096		30	3·376		30	7·596
	45	1·063		45	1,469		45	2·120		45	3·431		45	7·860
47	0	1·072	56	0	1·482	65	0	2·144	74	0	3·487	83	0	8·144
	15	1·082		15	1·496		15	2·169		15	3·546		15	8·449
	30	1·091		30	1·511		30	2·194		30	3·606		30	8·777
	45	1·101		45	1·525		45	2·220		45	3·668		45	9·131
48	0	1·111	57	0	1·540	66	0	2·246	75	0	3·732	84	0	9·514
	15	1·120		15	1·554		15	2·273		15	3·798		15	9·931
	30	1·130		30	1·569		30	2·300		30	3·867		30	10·38
	45	1·140		45	1·585		45	2·327		45	3·937		45	10·[illegible]
49	0	1·150	58	0	1·600	67	0	2·356	76	0	4·011	85	0	11·43
	15	1·160		15	1·616		15	2·385		15	4·087		15	12·0[illegible]
	30	1·171		30	1·632		30	2·414		30	4·165		30	12·71
	45	1·181		45	1·648		45	2·444		45	4·247		45	13·46
50	0	1·192	59	0	1·664	68	0	2·475	77	0	4·331	86	0	14·30
	15	1·202		15	1·681		15	2·506		15	4·419		15	15·26
	30	1·213		30	1·698		30	2·538		30	4·511		30	16·3[illegible]
	45	1·224		45	1·715		45	2·571		45	4·606		45	17·61
51	0	1·235	60	0	1·732	69	0	2·605	78	0	4·704	87	0	19·08
	15	1·246		15	1·749		15	2·639		15	4·807		15	20·82
	30	1·257		30	1·767		30	2·675		30	4·915		30	22·90
	45	1·268		45	1·785		45	2·711		45	5·027		45	25·45
52	0	1·280	61	0	1·804	70	0	2·747	79	0	5·144	88	0	28·64
	15	1·291		15	1·823		15	2·785		15	5·267		15	32·73
	30	1·303		30	1·842		30	2·824		30	5·396		30	38·19
	45	1·315		45	1·861		45	2·863		45	5·530		45	45·83
53	0	1·327	62	0	1·881	71	0	2·904	80	0	5·671	89	0	57·29
	15	1·339		15	1·900		15	2·946		15	5·819		15	76·39
	30	1·351		30	1·921		30	2·989		30	5·976		30	114·6
	45	1·364		45	1·942		45	3·032		45	6.140	90	45	229·2

APPENDIX B.

TABULATED STATEMENT OF TESTS.

(Tests how conducted and worked.)

Nature of Tests.	Orders to Distant Station.	CONNECTIONS.					Results how obtained.	Worked by Formulæ.	REMARKS.
		At Commutator.	At Testing Arrangement.	Branches.	Pos. Plug.	Neg. Plug.			
1	2	3	4	5	6	7	8	9	10
* Partial Earth on single wire:— Cre or Cdn ...	Cre or Cdn	Bring wire to I.	Plug 3, 4, 11, 12, 13, 15, 19.	A=B=1000	6, 7.	8, 9.	Press Bty. key. then Galvr. key, and adjust W to obtain balance.	$X = I\sqrt{\frac{(I-W)g}{W-w}} \times I-w$ $L = I + \frac{(I-W)g}{W-w} - 2i.$	
Nsn ...	Nsn ...	Ditto ...	Ditto ...	B=1000, A=1000, 100, or 10	Do.	Do.	Ditto ...		
Dead Earth on single wire:— Cdn to fault ...	......	Ditto ...	Ditto ...	A=B=1000	Do.	Do.	Ditto ...	RF ÷ PM (of previous test) =RD.	
Earth, Dead or Partial, when 2 wires available:— Loop ...	Loop "Good" wire with "Faulty" one.	Bring "Good" wire to I, faulty wire to II.	Plug 3, 11, 12, 13, 15, 19.	Do.	Do	Do.	Ditto ...	$X-y \div 2 = RF$ $X \div RL$ [both wires] $= PM$. $\therefore RF \div PM = RD$.	1st Test (x). 2nd Test (y). (If y < o, reverse connections at Comtr) and add results.
Localization ...	......	......	Plug 4, 11, 12, 13, 15, 19.	Do.	Do.	Do.	Ditto ...		
† T on 2 wires when only 2 wires available:— Cdn one wire ...	Cdn wire No. 5 and Nsn No. 4.	Bring wire No. 5 to I, and Nsn wire No. 4.	Plug 3, 4, 11, 12, 13, 15, 19.	Do.	Do.	Do.	Ditto ...	$X + y \div 2 = RF$. $X \div RL$ (of wire No. 5) $= PM$. $\therefore RF \div PM = RD$.	1st Test (x).
Locln. ...	......	Bring wire No. 4 to III, let wire No. 5 remain as before.	Plug 5, 11, 12, 13, 14, 15, 19.	Do.	Do.	Do.	Ditto ...		2nd Test (y). If balance cannot be obtained thus put earth to I, and line to II. Formula $\frac{x-y}{2}$ Remove plug from 5.
T on 2 wires when another Good wire available:— Loop ...	Loop "Good" wire with one faulty wire, Nsn the other faulty wire.	Bring "Good" wire to I, looped faulty wire to II, Nsn the other faulty wire.	Plug 3, 11, 12, 13, 15, 19.	Do.	Do.	[illegible]	Ditto	$X-y \div 2 = RF$. $X \div RL$ (of wires to I. & II of the bridge)$=PM$ $\therefore RF \div PM = RD$.	1st Test (x)
Locln. ...	......	Leave Good and faulty wires as above, bring the other faulty wire to III.	Plug 11, 12, 13, 14, 15, 19.	Do.	Do.	Do.	Ditto ...		2nd Test (y).
Insulated Break:— Nsn to fault.	......	Bring wire to I.	Plug 3, 4, 11, 12, 13, 15, 19.	B=1000 A = 1000, 100 or 10	Do	Do.	Ditto ...	$n = {}^{i}\,l$	

REFERENCES TO FORMULÆ.

RF means Resistance to fault.
PM „ Cdn per mile.
RD „ Reduced distance to fault.
RL „ Reduced length.
n = distance to fault.
i = the absolute insulation of the whole line known from previous tests (if possible select a test conducted during similar weather, and at the same hour of the day).
I = the absolute insulation of the broken wire.
l = length of the wire.

NOTES.

* Earth on a single wire may also be tested if there is an Inter. Station between the Testing Station and the fault as follows:—

Take cdn (W) and nsn (I) to Inter. stn. then jn. Inter. stn. drt. and test cdn. (W) to fault work by following formula:—

$$X = \frac{I\ (W-w)}{I-w} \text{(Res. from Inter. Station to the fault).}$$

† This may also be tested thus:—(Say Nos. 4 and 5 are in T).

1st. Test.—Cdn 5 and Nsn both ends of 4; call this W^{I}.
2nd. „ —Loop through the fault, with Nsn both 4 and 5 at the distant end; call this W^{II}.
3rd. „ —Cdn 4 through the fault, with Cdn 5 and Nsn 4 at the distant end; call this W^{III}.
Work by formula:—

$$X = \frac{W^{I} + W^{II} - W^{III}}{2} \text{ (Resistance to fault from the Testing Station).}$$

The X, Y and Z EARTHS should be tested with one minotti cell, but if it not sufficient to overcome the natural current opposing it, two or more cells may be used (joined parallel to reduce their internal resistance). Each pair of Earths should be successively joined to I and II of the BRIDGE and tested with *positive* and *negative* currents. The mean of the *positive* and the *negative* readings should be taken and worked as follows:—Say

$$\left.\begin{aligned} X + Y &= W \\ X + Z &= W^{I} \\ Y + Z &= W^{II} \end{aligned}\right\}$$ These represent the mean of the total resistances unplugged in the W. Box for each test.

From the above, separate values of X, Y and Z may be found as follows:—

$$X = \frac{W + W^{I} - W^{II}}{2}$$

$$Y = \frac{W + W^{II} - W^{I}}{2}$$

$$Z = \frac{W^{I} + W^{II} - W}{2}$$